THE CONSTRUCTION
OF
ROADS AND PAVEMENTS

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PREFACE

"The Construction of Roads and Pavements" was written to meet the need for a concise presentation of approved practice in the construction of roads and pavements and of the principles involved.

The book is intended primarily for use as a text in a two or three-hour course in roads and pavements, but numerous tables and typical designs and specifications have been included that should add to its value as a reference book for highway engineers.

The ultimate object of all highway engineering is the construction of durable and well-designed roadway surfaces. The attainment of this object involves selecting and testing the materials, assembling those that are suitable, and incorporating them in the roadway surface. A knowledge of the construction of roads and pavements is therefore the basis of highway engineering.

Much of the material used in the text has been prepared from notes that have been accumulating for several years. During that time the author has attended numerous conventions of highway engineers and has often discussed the various problems of roadway construction with engineers with whom he has been associated. Doubtless many of the ideas expressed in the text have thus unconsciously been absorbed. A considerable amount of material has been obtained from current periodical literature and acknowledgment has been given for material abstracted from the writings of other engineers.

The author is especially indebted to Mr. T. H. MacDonald, Chief Engineer of the Iowa Highway Commission, for his assistance and encouragement; to Mr. J. W. Eichinger, Editor of the Iowa Service Bulletin, for valuable suggestions and especially for furnishing photographs for cuts; to the Illinois Highway Department for much valuable data, and to a score or more other highway engineers who have furnished plans, specifications, photographs or data on construction.

Special acknowledgment is made of the very valuable assistance of Mr. C. S. Nichols, assistant to Dean of Engineering, Iowa State College, who has assisted in the preparation and arrangement of the manuscript.

T. R. Agg.

August, 1916.

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CONSTRUCTION OF ROADS AND PAVEMENTS

CHAPTER I

THE DEVELOPMENT OF HIGHWAY SYSTEMS

There are, in the nature of things, more restrictions on the social activities of those who live in the rural districts, than on those who live in the towns, due to the distances the residents must travel if any considerable number are to meet together. The nature of rural activities and the sequence of farming operations restrict social opportunities to a degree while the crop season is in full swing. During the part of the year when farming operations permit some leisure, weather and the condition of the highways determines the ease and comfort with which social gatherings may be attended. In the towns and smaller villages, social life is more or less dependent upon the participation of those who live in the surrounding farming community and anything that prevents the country people from joining with the village in social affairs is a deterrent to healthy community intercourse.

A certain amount of social intercourse is a necessity to all men and in the rural communities it is particularly salutary to the health and happiness of the people that reasonable opportunities be presented for social meetings. There is plenty of evidence in the records of sanitariums and asylums to show that isolation and the resulting loneliness have had a tendency to disturb the mental balance and undermine the health of those who have lived in the partial isolation of the farm.

With the advent of the rural telephone and free mail delivery, the automobile and parcels post, conditions of living are much improved in the rural communities, but nothing takes the place of social gatherings and the opportunity for them depends largely upon the condition of the highways. If the highways are well kept and comfortable to travel at all seasons of the year, that

will do much to encourage frequent social gatherings and the whole life of the community will respond to the interchange of ideas and experiences that will thus be had.

There are those who have secured a competence on the farm and who would prefer to continue living there were it not for the lack of social opportunities, but this lack is often one of the principal things that induces them to move to town. They are usually the class of citizens who are most progressive and whose example is invaluable to their neighbors on account of the advanced methods of farming they follow and their enlightened attitude toward all rural problems. Good highways which will give them free intercourse with their neighbors and with the towns, will do much to induce this class of citizens to stay on the farm to the advantage of the commonwealth and to their own profit.

Highway improvement also has an important bearing on the educational opportunities of the children who live in the country. They should have as good opportunities for an education as is offered to children in the towns and, indeed, the solution of the problem of furnishing an adequate supply of food stuffs to the nation depends upon the proper education of the children in the rural communities. Educators think that in order to give adequate training in the country districts, group schools are a necessity and the success of group schools depends upon adequate facilities for the children to get back and forth, that is, upon there being good, serviceable roads throughout the district tributary to the schools.

Many institutes, farmers' clubs, and college extension activities have developed in recent years, which have a broad educational value, and all depend for success upon the possibility of people assembling at some convenient place for instruction and discussion. They will do this only when roads are reasonably good.

While the various social and educational aspects of the rural highway problem are of great importance, they are less so than is the transportation phase. Highways should be considered as important links in the transportation system of a nation and as such it is vital that they be maintained in usable condition throughout the year. In some communities serviceable roads may be nothing more than well-drained, well-dragged earth roads; others may furnish traffic requiring gravel or macadam,

or roads of the highest degree of durability such as is furnished only by brick or concrete. No matter which may be required, the roads are a part of the equipment for the transaction of business and any reasonable expenditure of money in road construction is justifiable as a matter of enlightened public policy.

Instances have frequently been noted where the system of farming and the whole rural business life has been transformed after the highways had been improved and, in general, both the rural population and the urban population of the market center of the district have been greatly benefitted by the changed conditions. The financial benefits derived have been many times the cost of the improvement of the highways.

It is particularly true that the territory tributary to the larger cities (which should be a source of supply for the more perishable food stuffs) is quite often cut off from its most logical market by the poor conditions of the highways over which the supplies must move. Such a condition causes a direct financial loss to both producer and consumer which in a few years will aggregate a sum far in excess of the cost of any reasonable system of highway improvement that would be necessary to serve such a community.

From the social, educational and transportation standpoints, then, it is apparent that money expended for highway improvements is a good investment. Such an expenditure, however, should be made only after a careful analysis of the many factors that will have a bearing on the adequacy of the resulting road system. Haphazard expenditures, on the other hand, can never produce results of commensurate value.

The public highways of a commonwealth comprise a great system of routes for transportation and should be constructed and administered as such. In sparsely settled districts they are primarily routes which serve the rural communities for the necessary intercourse between farm and market center and are infrequently used. In such places insufficient funds are available for the construction of other than the cheapest earth roads and those who use the highways for business or pleasure must of necessity accommodate themselves to the varying conditions of the highways. The important consideration in such a community is not the possibility of building roads designed for low tractive resistance and long life but is rather the possibility of getting the most systematic and economical expenditure of the

meager funds alloted to highway purposes. The problem is one of administration rather than one of design and construction. But when only small sums are available it becomes the more important to study carefully all of the economies possible and to make extraordinary use of the materials and equipment at hand. Such a study may result in sand-clay or gravel roads being built as has been the case in many sections of the United States, or it may result in the development of a new device or method of construction being adopted. Such conditions resulted in the invention of the split-log drag and the road planer, which have proven so useful in earth-road maintenance.

The more thickly settled the district the more important this transportation system becomes. In those sections of the country which are so densely populated that there is a succession of towns and cities the public highways are a vital part of the transportation system.

The public highways, in such instances, are utilized for both business and pleasure by great numbers of citizens and assume an importance that rapidly increases each year.

Obviously in populous districts large sums of money may be had for highway improvement and, moreover, the types of roads that would suffice for sparsely settled country are totally inadequate. The problem then becomes one of construction as well as one of administration and the greater the cost of roads the greater the care that should be given to the selection of type and to the character of the construction.

In general, public highways serve first of all the territory, be it large or small, which is tributary to some market center. Many roads may converge to such a city and on the outlying roads of the system the traffic may be light. Nearer the city the traffic increases until some of the roads are carrying a traffic fully as heavy as many city streets.

Besides the local traffic there is a considerable amount of neighborhood traffic which uses the highways between adjoining towns both for business and pleasure and this class of traffic is constantly increasing in amount and importance. In many places the commercial motor truck is being used for transporting goods a distance of 30 miles, and this class of traffic will doubtless increase rapidly when the highways are improved sufficiently to make it possible. Motor cars, for pleasure or business trips, have greatly extended the territory of business establishments

and have thereby greatly increased the amount of neighborhood traffic on the public highways.

Public highways are also receiving an appreciable amount of through motor-car traffic, particularly those roads that constitute direct routes between the larger cities. This class of traffic knows no limitations as to distance traveled, passing entirely across a state or several states or even entirely across the continent. It also will greatly increase in volume as the condition of the highways is improved.

Since the traffic on the public highways is so diversified in character and consists of so many small units under separate ownership, the tremendous handicap and loss due to poor roads does not make itself felt at once. It is apparent, nevertheless, that the amount of energy required to move a load over a public highway is of vast importance. If only a few vehicles use the road each day the cost for power may be unimportant economically, although it may be a serious matter to those who use the road. If, however, the number of vehicles that pass over the road is large then the amount of energy expended is an important consideration.

In general, hard surfaced roads are of lower tractive resistance than earth roads but the aggregate energy saving on a hard surfaced road over an earth road will be small or large depending upon the amount of traffic that uses the road.

Numerous attempts have been made to estimate the decrease in the energy expended and consequent reduction in the cost of hauling that results from road improvement. Such estimates have little value due to the great diversity of conditions under which hauling is done. If a certain quantity of material is to be transported daily over a certain road the cost can readily be computed, but for intermittent hauling, often with part loads, and at times that can be chosen to suit the condition of the roads, the cost can not readily be determined.

The fact that it costs much less to haul a load on good roads than on bad roads is the one fact that is well established. Just how much less it costs is not known and really is not of first importance. Highway improvement is very often brought about by a desire for greater comfort and convenience rather than from a desire to save on the cost of hauling, although the fact that a saving in hauling costs results, is undoubtedly a factor in bringing about all road improvement.

ADMINISTRATION OF RURAL HIGHWAYS

The administration of highways like the use of highways, has undergone continual change during recent years.

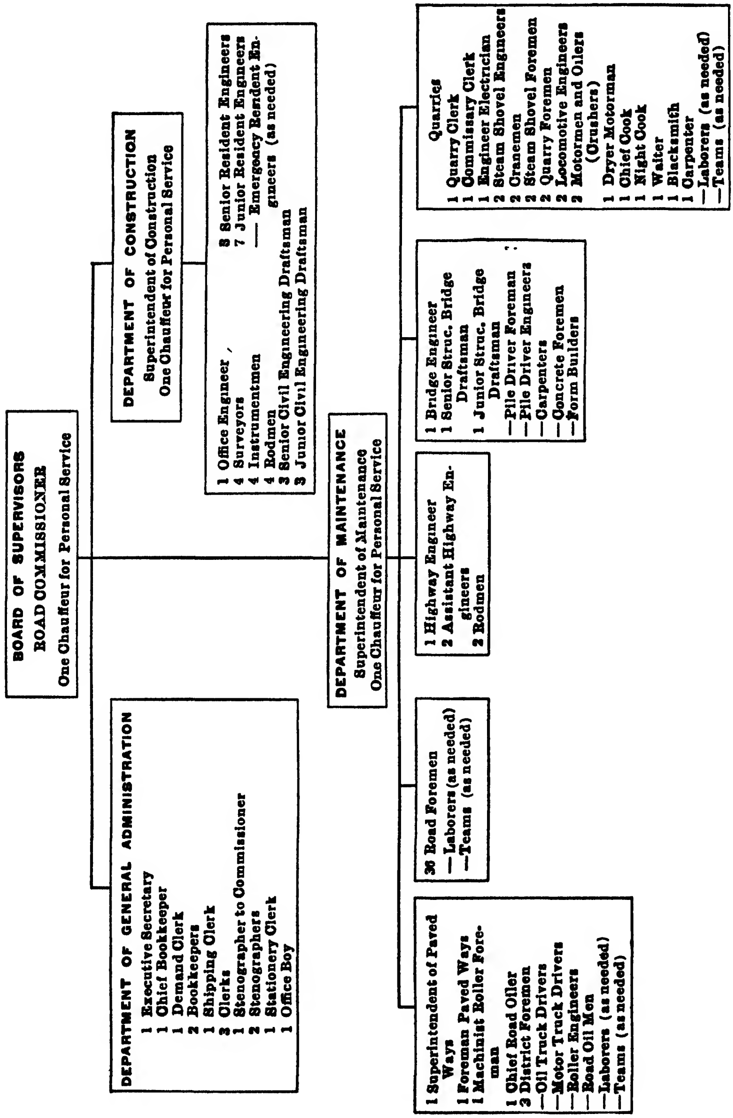


FIG. 1.—Organization of Los Angeles County Highway Department.

For a long time the control of the highways had been entrusted entirely to elective officials of the township or county. Such

officials gave only a part of their time to the administration of the road system. Standards of construction were exceedingly diverse among the various units and the efficiency of the maintenance methods adopted was generally low. So long as the roads were purely local in character there was little cause for complaint, because the officials were elected by the community and probably reflected the attitude of the public toward highway work.

With the development of neighborhood and through traffic, the condition of the highways became of more than local interest, resulting in many cases, in the concentration of authority in the county rather than in the township.

Finally the state was given some authority in the administration of highway affairs and a somewhat chaotic condition arose, with many questions of the jurisdiction of each unit more or less undefined. This has to a considerable extent been corrected by recent legislation, but still exists in some states.

In order to define more clearly the duties of each administrative body, the highways of many of the states have been classified and the responsibility for the care of each class of roads more or less clearly fixed.

I. Township or Town Roads.—This group comprises the purely local roads and is ordinarily under the jurisdiction of the township highway officials. In mileage it comprises about 80 per cent. of the total of the country, but probably does not carry to exceed 25 or 30 per cent. of the traffic of the country. Four methods of financing the improvement of all or a part of the township road system are in effect in the United States, the practice varying widely in the several states.

1. Entirely by the township.
2. Jointly by the township and the county.
3. Jointly by the township and the state.
4. Jointly by the state, county and township.

II. County Roads.—County roads are those highways in the county that are administered by the county officials. Not every state has such a system. Where it is in effect, the system generally comprises about 15 per cent. of the mileage of the county, but these roads carry 60 per cent. or more of the traffic of the county. Such roads are selected so as to include the main market roads and when taken over by the county, the township is thereby relieved of the necessity of caring for them.

The improvement of the county road system is financed in four ways.

1. Entirely by the county.
2. Jointly by the county and state.
3. By the county, township and state together.
4. The national government may be an additional party in any of the above groups.

III. State Roads.—State roads are those main highways that are improved largely or entirely at the expense of the state. In general they comprise about 5 per cent. of the mileage of the state and carry a relatively large amount of traffic, only a small percentage of which is of local origin. Only a few states have as yet established such a system of roads. The national government may participate in the improvement of state roads.

ADMINISTRATIVE AUTHORITIES

I. Township.—The township roads are under the jurisdiction of an elective board, generally consisting of three men. In some states the elective officials delegate the supervision of township road work to a statutory township superintendent who is employed by them. The elective officials receive a per diem and the superintendent is paid a monthly stipend.

II. County.—The county highway affairs are generally administered by a county board which is elected by the voters of the county and which is designated by various titles in the several states. Some states provide that the county court shall designate special commissions for expensive road-improvement projects.

The elective boards have many county affairs to look after and in some states the management of road work is delegated to a statutory county engineer or county superintendent who is employed by them. The county board members receive a per diem for their services. The county engineer or superintendent is paid a per diem or is employed by the year, and in some states must be an engineer and in others is not a technical man. The size and nature of the county organization depends upon the amount and character of the road improvement being carried out. Fig. 1 shows the organization in a county carrying out a large construction program, and having a considerable mileage of heavily traveled roads to maintain.

III. State.—State highway affairs are administered by a state department which consists of one or more commissioners and an organization of highway engineers. The commission is elected in one or two states, but is generally appointed by the governor. The number of men comprising the commission varies from one to five, and the service is gratuitous in some states and in others each commissioner is paid a statutory salary. The engineering force in the state department is employed by the commission either directly or through the medium of a civil service body

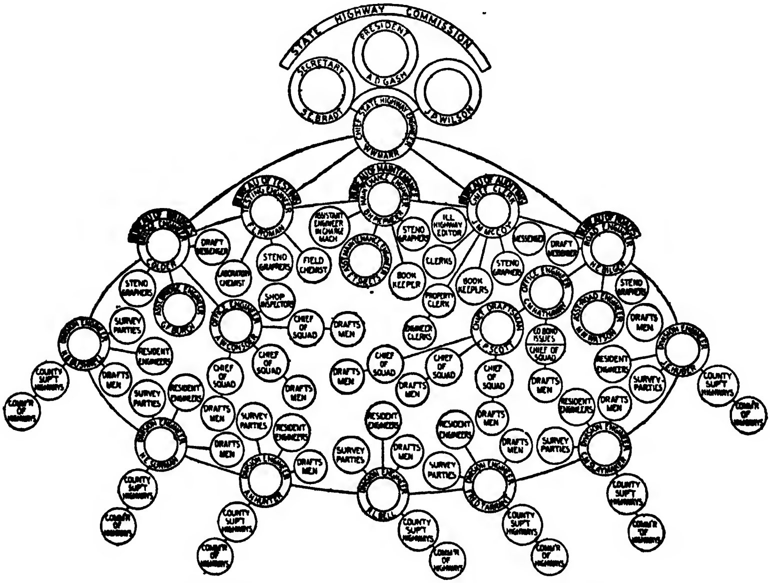


FIG. 2.—Organization of Illinois State Highway Department.

Fig. 2 shows the organization of a state department that is carrying out an extensive construction and maintenance program. Fig. 3 shows the organization of a model highway department.

FINANCE

Direct Taxes.—The cost of highway construction and maintenance is paid in part from funds derived from taxes levied on all taxable property in the township or county. Funds so obtained are generally expended indiscriminately in the political division in which they are obtained, for the ordinary upkeep and extension of the highway system. In some instances funds

obtained by general taxes are expended in hard surfacing or other expensive improvements on a few sections of road or for paying the community's part of the cost of improvements on state-aid or county-aid roads.

Special Taxes.—In many states it is possible for either the county or the town to levy a special tax for certain classes of permanent highway improvement. Almost invariably it is necessary to have such levies approved by a vote of the property owners of the political unit affected. Special taxes must in general be expended for certain definite and stated purposes and not for the general upkeep of roads. These taxes are often levied to provide for the local allotment of the cost of state-aid roads.

State Aid.—When a part of the cost of road improvement is paid from state funds the money so expended is known as state-aid money. State aid, where it is in effect, is extended for the improvement of main traveled roads such as those comprising state roads and the more important county roads. The proportion of the cost that is paid from state funds varies from one-third to about three-fourths of the total cost of the construction. The remainder of the cost is paid either by the county or the township or by the two jointly. Some state roads are built entirely at the expense of the state but these are not generally referred to as state-aid roads.

State Rewards.—The state-reward system differs from the state-aid system in that the roads are built by the county or township and, if when completed, they come up to a certain standard, the state pays a certain reward to the county or township. The amount so paid is generally fixed for each class of construction and varies from a few hundred dollars a mile to about $1,000 a mile. The state-reward system is merely a form of state aid, but the entire responsibility for the construction is placed on the political unit initiating the improvement.

National Aid.—The United States Government has already established a limited national aid for the improvement of post roads and has allotted small sums to several projects for the improvement of roads of this class. National aid is administered by the Office of Public Roads and Rural Engineering in much the same way that state aid is administered by the various state departments.

Automobile Licenses.—In many states owners of automobiles are required to pay a state license and the money so obtained is added to the road funds. In some states it is added to the

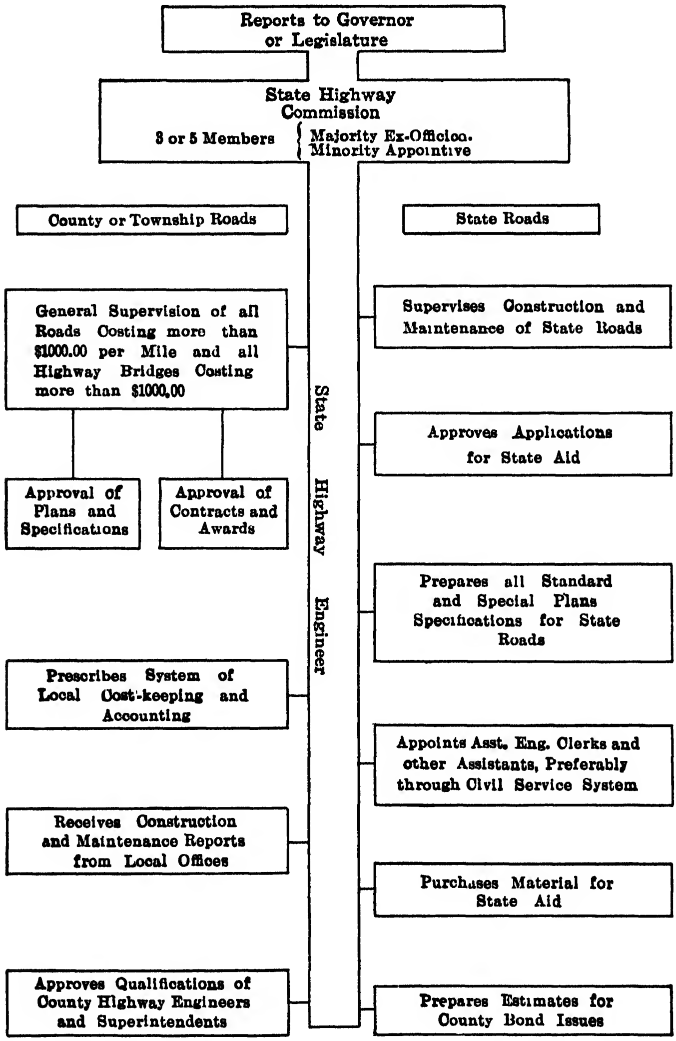


Fig. 3.—Outline of a model state highway department organization.

state-aid or state-reward funds and in other states it is distributed to the various counties or towns to be added to their road funds.

Bonds.—States, counties and townships each have issued bonds for highway construction but there are only a few states in which the township may do so. The county is permitted to issue such bonds in many states and a great many millions of dollars worth of such bonds are outstanding. Several states have also issued bonds for highway improvement. The permissible life of such bonds and the rate of interest is not at all uniform in the several states, but the practice has quite generally been to provide for relatively long term bonds. There is a growing belief that the bond method of financing road improvement is both logical and equitable, if the life of the bond is well within the useful life of the road.

Special Assessments for Rural Highways.—The special-assessment method of financing has long been employed in the cities, but has had limited application in connection with rural highways. Where it has been attempted, the principle has been to assess a small percentage of the cost against the adjacent farm lands for a depth varying from ¼ mile to 5 or 6 miles.

CITY STREETS

Pavements are as necessary for a city of any commercial importance as are railroads and it is taken as a matter of course that all except the least important residence streets in outlying districts will be paved. Transportation demands, convenience, cleanliness, and appearance are all potent factors in creating a desire for improved streets and pavements are laid as a matter of public necessity.

Cities and towns everywhere pave their streets as a matter of convenience and cleanliness just as they paint the houses or build sidewalks. Many streets are paved where the traffic is so small in volume that transportation needs alone would not justify it, but the other considerations are such that the residents are willing to pay for the improvement.

ADMINISTRATION OF STREET PAVING

Street paving is administered in a number of different ways in American cities, but in general is under the jurisdiction of an elective body, which delegates its authority to a subordinate department.

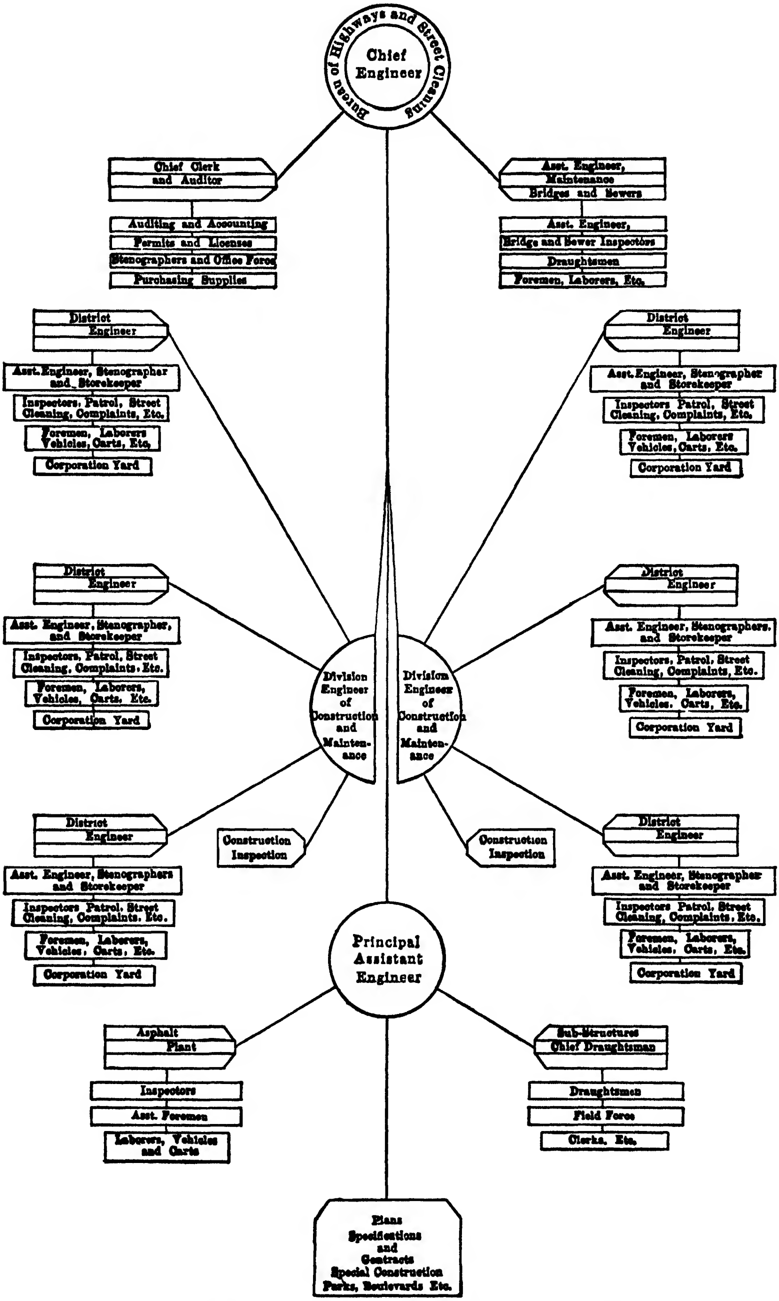


FIG. 4.—Organization of the Philadelphia Highway Department.

Where the affairs of a city are administered by a city council or board of aldermen, the paving is supervised by one or the other of the following organizations.

1. A committee of aldermen which is known as the Committee on Streets and Alleys, the Board of Local Improvements or by some similar designation. Final action on contracts is generally required of the entire board.

2. A special Board of Public Works which is either appointed by the mayor or is elected. Such boards generally have final authority in paving matters.

When the city is organized with the commission form of government, one of the commissioners usually has charge of public improvements, including paving and final action on contracts is by the commission.

Cities that are organized under the city-manager plan usually have a department for handling the street work which is subordinate to the city manager. The contracts are subject to approval of the city manager and the advisory board.

Street repairs and street cleaning are commonly administered by the same organization that is responsible for the construction of new pavements but the street cleaning is generally handled through a special bureau.

FINANCE

Special Assessments.—In most cities the cost of new pavements is borne largely by the owners of abutting property, which is assessed directly. In many cities the assessment may extend back halfway to the next street, but not farther than a specified distance. Various portions of the cost of new pavements and of repaving are borne by the city at large.

Payment for paving is by means of paving certificates or paving bonds which are issued as soon as the pavement is accepted. These evidences of indebtedness are payable in annual installments for a period of years and thus the property owner is given from 5 to 10 years for paying for the paving.

The variation in practice is indicated by the following excerpt:

New Paving[1]—
In 62 per cent. of these cities the property pays all.
In 6 per cent. the property pays 50 per cent.

[1] Report of Municipal Committee of Cleveland Chamber of Commerce.

In 10 per cent. the property pays more than 50 per cent. and less than 60 per cent., except in one city, where the property pays 30 per cent.

In 22 per cent. the city pays all.

Repaving—

In 42 per cent. of these cities the property pays all.

In 10 per cent. the property pays 50 per cent.

In 8 per cent. the property pays between 50 and 100 per cent.

In 40 per cent. the city pays all.

Approximately 25 per cent. of the cities pay the major part of the original paving, while 40 per cent. of the cities do the major part of repaving.

SELECTION OF PAVEMENTS

The type of pavement for a street is selected in many ways as will be noted in the following outline. Generally the city authorities have the final word in the matter, although this is not always true.

Methods of Ordering Pavements.[1]—In 50 per cent. of the cities heard from, any city street may be ordered paved by the common council, by a majority vote varying from one-half to five-sixths, it usually being two-thirds. In 30 per cent. of the cities, no new paving can be ordered except by a petition of from one-half to two-thirds of the abutting property owners. In 10 per cent. of the cities, the common council is permitted by ordinance to order a stipulated amount of new pavement each year.

How Type of Pavement is Selected.—In only 15 per cent. of the cities do the abutting property owners have the final decision in selection of type of pavement. In a few cases, the common council or even a single alderman has the deciding power. In about 80 per cent. of the cities, however, the type of pavement is selected by a paving commission, highway or engineering department, after due consideration of the wishes of the abutting property owners.

HIGHWAY ENGINEERING

It will be apparent from the foregoing that in the construction of roads and pavements many problems peculiar to that field of engineering will arise. Preliminary investigations, the selection of type of construction, the design of roads and pavements, the

[1] Report of Committee of Chamber of Commerce of Syracuse, N. Y.

preparation of specifications, and the supervision of construction and maintenance all require a knowledge of the principles that have been evolved by experience and experiment. The field of the highway engineer is thus apparent, and with the rapid expansion of systems of surfaced roads, and the greater attention that is being given to systematic maintenance both for street pavements and rural highways, the need for trained men is obvious.

CHAPTER II

SURVEYS AND PLANS FOR ROADS AND PAVEMENTS

ROAD SURVEYS

The completeness and detail with which a road survey should be made depends upon the character of the improvement contemplated and whether the work is to be done by contract or by force account. Surveys by various engineers differ in many respects even though made for the same class of construction, and it is not possible to standardize them because of that fact. So far as the actual work of making the surveys is concerned, no principles are involved that are not involved in making surveys for other engineering projects. As with other surveys, the information obtained and the method of tabulation are adapted to the needs of the work in hand.

For the purposes of discussion it is convenient to divide all surveys into four general classes: (*a*) reconnaissance surveys; (*b*) surveys for earth-roads to be graded by force account; (*c*) surveys for hard-surfaced rural highways; and (*d*) surveys for paving. These represent four broad classes of surveys which inevitably overlap to some extent.

Reconnaissance Surveys.—These surveys are of two kinds, the first of which is identical in purpose with the reconnaissance survey made in railroad work. Its purpose is to find the best location or route for a new highway or relocation of an old one. This type of survey needs no explanation.

The second type of reconnaissance survey is one that has been adapted primarily to highway work and has for its purpose the selection from among several roads, of the most feasible for improvement. It involves the examination of the road to secure data for the preparation of a map showing the various physical characteristics such as bridges, culverts, embankments, cuts, hills, the apparent width of right-of-way, the character of the soil and any other fact that would have a bearing on the selection of a route.

Apparently such a survey differs widely from the ordinary reconnaissance and yet it serves substantially the same purpose,

namely, the selection of a tentative route. The survey is made by walking or driving over the road. Distances are obtained by the pedometer or odometer and checked by intersecting roads and survey monuments when these are encountered. The notes are kept in the ordinary field book upon which the route has already been platted from existing maps so that it remains only to fill in the detailed information.

Surveys for Earth-road Construction.—For earth-road grading, especially blade grader or elevating grader work to be done by force account, it is not always necessary to make complete detailed surveys. Grading done by force account is not usually finished very closely to grade, nor will it be necessary to balance earthwork on the plans because adjustments can be made in the field as the work progresses. The object of this kind of a survey is to give an approximate grade for the outfits to work to so that drainage will be assured and reasonable gradients result. The transit survey usually consists in running a center line and locating fence lines, bridges, culverts, and other physical characteristics relative to this line and to the adopted stationing. Houses, entrances to farms, trees, pole lines, bridges and similar physical characteristics are indicated as well as the type of soil encountered.

The level survey consists in running a center-line profile, and possibly a profile in each ditch. If a section is encountered where it appears that a considerable change in grade will be desirable, cross-sections are taken at 100-ft. stations and at intermediate breaks in grade if such occur.

This kind of a survey is suitable for force-account grading and is permissible where funds are not to be had for a more complete detailed survey. It is used especially on earth-road grading or low-grade surfacing where the local conditions are such that the requirements are not exacting.

Complete Detailed Surveys.—The complete detailed survey is made on state and county roads that are to be brought to an exact grade or are to be surfaced with a high-class roadway. *It is a requisite for the preparation of suitable plans for contract road work of any class.* The survey includes the accurate location of all the physical and topographical features that may affect the design. The center line of the road is found by means of the permanent monuments or the records filed when the road was established. The topography is taken with this line

or one parallel to it as a reference line. Bridges, culverts, fences, traveled way, ditches, lines of tile, pole lines, trees, entrances and all similar features of the highway are noted. Cross-sections are taken every 100 ft., and more frequently if the topography demands it, together with the elevations of beds of intersecting streams, elevations of culvert tops, bridge floors, tile outlets, etc. In other words, the survey is complete and detailed in every respect.

This sort of survey is to be recommended wherever extensive improvement is undertaken and is a necessity for contract work which is let on a unit price basis. The scope of such a survey is indicated by the following set of instructions:

DIRECTIONS FOR MAKING ROAD SURVEYS[1]

Transit and Location Survey.—The transit line should be established following approximately the center line between fences. At a distance of every 100 ft. on this line temporary points or stations are to be established and at plus stations where it will be necessary to take a cross-section on account of changes in ground. These points can readily be preserved for several hours by driving a heavy spike through a piece of cloth into the ground.

Opposite the stations established in the road and at points far enough removed to insure they will be undisturbed by construction or travel, stakes should be driven. These stakes should be 24 by 2 by 1 in. and driven to a depth of 15 or 18 in. Stakes should be numbered beginning with 0, each 100 ft. to be a unit; plus stations are to be marked with the number of the previous station, with 25 or 58, etc. In numbering, hard kiel or carpenter's pencil should be used. The distance from the center of the stake to the station point on the transit line should be measured to the nearest 0.1 ft. and recorded with the notes. Station 0 must be referenced to some permanent monument or to established lines, *i.e.*, as so many feet south of the south corporation line of the village of Oblong on the center line of Range road in Township of Oblong, Crawford County, or 50 ft. north of corner stone at intersection of Alton road and South road, Central Township, Bond County, or on the corner stone at common corner of sections 1, 2, 11, and 12, — Township, — County.

[1] Manual of Instructions to Engineers, Illinois Highway Commission.

Wherever it is necessary to make a deflection in the transit line, the transit is to be set up at the point of deflection, and the angle of the course ahead with that of the rear course measured, always measuring from the back sight around to the right to the fore sight. The angles are to be measured to the nearest minute and where local disturbances do not prevent, magnetic bearings at each course should be observed. As a rule, deflection points should be made at even stations or half stations, a half station being designated by the number of the previous station with +50.

At all deflection points stakes should be set on both sides of the road in a line through the point of deflection at right angles with the back course. These stakes will be used as reference stakes and should have a tack in the top and should be driven flush with the ground and another stake driven nearby for a marker.

After the location of the transit line as described, off-set measurements are to be taken at each station or oftener, if necessary, locating the sides of traveled way, fences and walls, ditches, and all other features of the location that in any way affect the proposed construction. Remember that no harm is done if too much is included, but an omission may cause much additional expense.

Measurements should be taken locating all bridges, culverts and cross and longitudinal drains with their abutments or retaining walls, an arrow showing the direction of the flow. The clear span and clear depth of streams should be shown and a concise description of the structures given with details as to its present condition and recommendations for its reconstruction if it is to be rebuilt.

The location of all crossroads, crosswalks, private entrances and buildings near the road should be given. Landowners' or tenants' names should be obtained and division fences located.

Remember that the principal information desired is the location of the traveled way, fences, stakes and notes on the character of bridges, culverts and other drains. When necessary, make a special bridge inspection report for each bridge to be rebuilt. Places in the road habitually bad, spongy, or so-called bottomless, should be located, giving stations.

Levels.—After the transit and location surveys have been made, the levels are run as follows:

The levels are to be run with an engineer's level. Place permanent bench marks at either end of the work and at convenient intermediate points which are to be established well out of the way of any construction. The number of bench marks should be at least four to the mile and more may be required. Bench marks should be on permanent objects on which a rod can conveniently be held, so marked that they can readily be identified in the field. The roots of trees with low hanging limbs are not convenient nor is a point so far back from a line of trees along a road that all view of the bench mark is shut off, except from a point directly opposite it.

A line of check levels should be run touching every bench mark, and separate notes should be kept of the check survey.

Readings for ground elevations should be to nearest 0.1 ft. Ground elevations are to be taken at the center of the road at each station of 100 ft. and as much oftener as may be necessary to show irregularities in the profile.

At each section where a center reading is taken, side readings are to be taken to show accurately the cross-section of the road. Six or eight readings usually will be necessary. To take a cross-section, first take reading of the rod on top of the stake and on the ground at the stake at that particular station; other points across the line of the road are then taken to show the true shape of the banks, gutters and ditches on each side and the road between. The distance of each rod reading from the stake is to be recorded as the numerator of a fraction and the reading itself as the denominator.

Elevations are to be taken of the following points:

(*a*) The bottom of openings at each end of all culverts, indicating them as east and west or north and south ends, etc.

(*b*) Bridge floors and tops of abutments or bridge seats.

(*c*) The bottom of ditches at the entrance and exit and about 100 ft. from either end of a culvert or bridge so as to give the profile of the stream bed near the culvert.

(*d*) High and low water in stream (estimated).

(*e*) Water surface of streams as found.

(*f*) One hundred feet in either direction on crossroads or intersecting roads and important entrances.

(*g*) Rails of intersecting railroads or trolley tracks.

A center profile shall be run for 300 ft. beyond the end of the survey and 300 ft. back of the starting point.

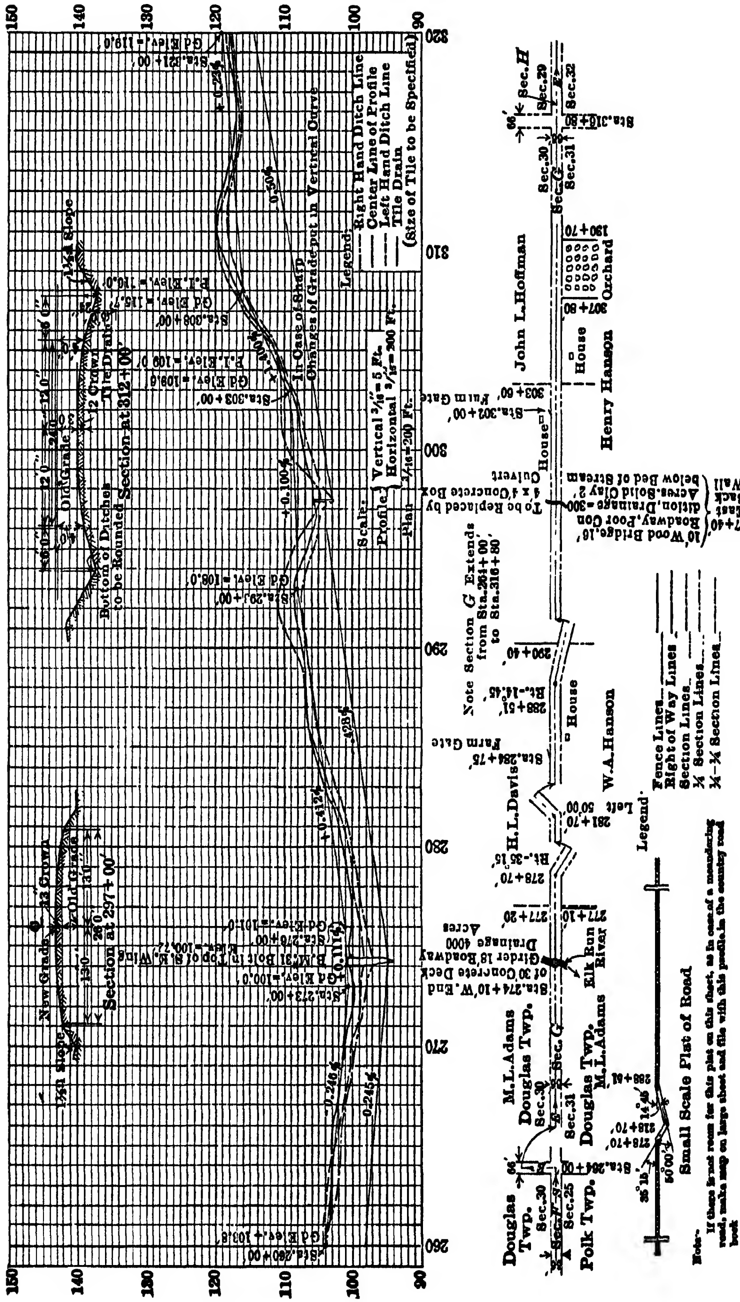


FIG. 5 —Plan for blade grader road construction.

ROAD PLANS

As might be expected, the plans prepared for road improvement vary in completeness and form among the various engineers and state departments. In general makeup they are much the same, consisting of a plan and a profile always, and frequently being accompanied by the cross-section for each station.

Profile.—A center-line profile is usually shown. It is sometimes the profile of the finished roadway, sometimes that of the foundation for the hard surfacing and sometimes a "grade" profile or profile passing through the balance line of the cross-section. Probably the most common practice is to show the profile of the finished surface.

The scale to which the profile is drawn also varies greatly. A scale of 8 ft. per inch vertically and 100 ft. per inch horizontally, or of 200 ft. to the inch horizontally is often used.

A horizontal scale of 40 ft. to the inch and a vertical scale of either 8 ft. to the inch or 4 ft. to the inch is also widely used and is probably the most satisfactory. Profiles drawn to this scale are voluminous and inconvenient to handle in the field, but are desirable from the standpoint of design.

The profile of the existing road surface and the established grade line are always shown and sometimes the profile of the ditches. The profile should also show all bridges and culverts, lines of tile and catch-basins. The location of bench marks and their elevation is given and the elevation of the established grade line is marked at every break in the grade line and sometimes at every station. The name of the road, the date of the plan and the scale are essential parts of the plan.

Plan View.—The plan view is usually on the same sheet as the profile and the horizontal scale is the same as the horizontal scale of the profile. The plan view is sometimes broken at turns or deflections and the center line maintained as a straight line so as to keep the plan on the sheet. On this view is shown the existing features such as fences, culverts, bridges, houses, driveways, intersecting roads, and such other information as may assist in the design. The lines of the hard surface and the location of any bridges or culverts to be built are also shown.

Cross-sections.—The cross-sections are platted in computing the quantities of earth work and are of use in construction in showing where surplus material is found and where it is to be

moved to. Usually the area of each cross-section and the quantity of material between sections is indicated. The sections are platted to a scale of 10 ft. per inch, 8 ft. per inch, or 4 ft. per inch. The larger the scale the more accurately the cross-section areas can be obtained, but the sections become exceedingly voluminous if platted to a scale of 4 ft. to the inch. Figs. 5, 6, and 7 show typical road plans.

SURVEYS FOR PAVING

The surveys made as a preliminary to paving must be made with greater accuracy and detail than is required of surveys for road work. Whereas in road work the accuracy required is seldom greater than 0.1 ft., except on bench marks and grade stakes, in surveys for paving the measurements must usually be made to 0.01 ft., and the elevations except on cross-sections are taken with equal accuracy. At intersections and where the paving and curbing are fitted onto previously constructed improvements such as sidewalks and sewer openings and where buildings have been constructed without due regard to a future pavement, it is desirable to have exact information as to these existing structures. As with the road survey the topography is located with reference to the transit line which is run in as long tangents as circumstances will permit. Property lines are accurately located from official maps and recorded surveys In surveys for pavements the block is usually the unit, although 50- or 100-ft. stations are frequently established and cross-sectioned for determining the quantities of earth work. The transit and level surveys are made as described above, except that all the work must be done with much greater accuracy. Usually the survey must include those streets that intersect or are an extension of the ones to be improved. This is to insure that further paving operations will be correlated with those for which the survey is being made.

PLANS FOR PAVING

Plans for paving work include the plan and profile and one or more typical detailed cross-sections. The scales used vary as with road plans but either 40 ft. or 80 ft. to the inch is more often used than any other scale for the plan view. The profile

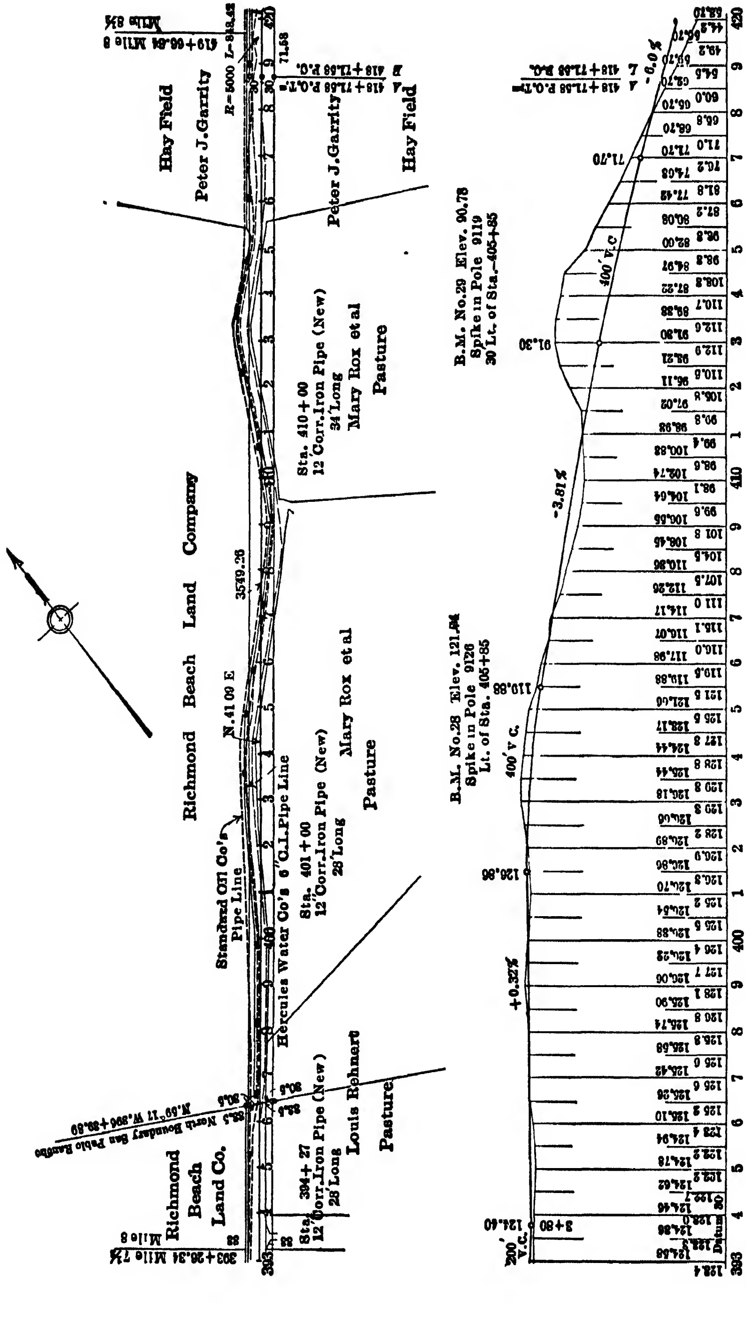


Fig. 7.—Plan for state road construction.

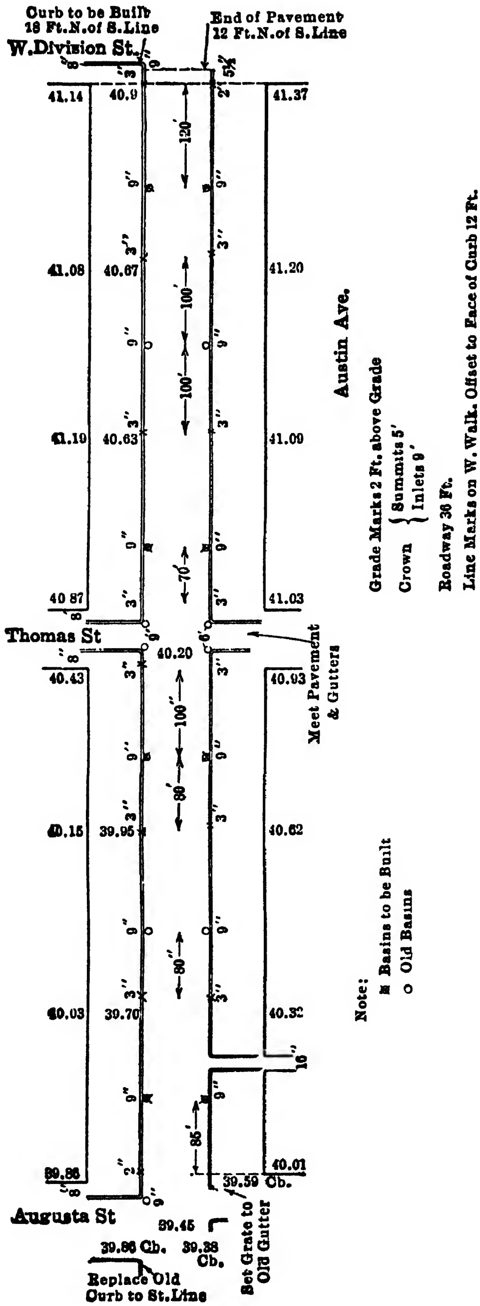


FIG. 8.—Plan for paving, city of Chicago.

is platted to the same horizontal scale as the plan view and the vertical scale is usually either 4 or 8 ft. per inch. Since the plans are furnished for the guidance of the engineer who lays out the work, all features of the construction should be shown in detail with all necessary data as to location and size. Details should be shown for intersections requiring special treatment and for catch-basins, inlets, manholes, and any other features requiring special treatment. Fig. 8 is a typical pavement plan.

Special Surveys and Plans.—Surveys made for mapping a city, or for establishing property lines and building lines and surveys to be used for developing city plans or for extending existing maps require elaborate treatment, and the establishment of base lines and triangulation systems for control. These are made in the same general manner as any other exact topographical survey and with the same exactness. The resulting maps are platted to whatever scale is most suitable for the particular case. Each problem of this sort must be worked out in accordance with the conditions encountered and the objects sought.

It is desired to emphasize the fact that surveys for roads and pavements do not present any new fundamental problems. Such special features as are introduced have to do with the details of the work rather than with underlying principles. Many convenient short cuts in taking the survey data and in working them up have been developed, but these are all adapted to special conditions and are not of general importance.

CHAPTER III

THE DESIGN OF RURAL HIGHWAYS

CLASSIFICATION OF SOILS

General Characteristics of Soils.—In earth-road construction, the material used is the soil which is found on the public highway to be improved, and this material varies greatly throughout the country, and, indeed, often varies considerably on a single mile of public highway.

From the road builder's standpoint there are certain characteristics which are common to many soils, although these soils differ very widely from the agriculturist's standpoint, and certain broad principles of highway construction can be laid down that can be applied with some modifications to all soils in these groups.

Most of the studies of types of soils have been made from the agriculturist's standpoint, and the classifications so made are of little interest to the road builder. The names given to the various kinds of soils by the scientist often differ from the colloquial name, and the local name given to the soil in one community may differ from the local name given to the same soil in some other community. It is, therefore, of little value to the road builder to study types of soils from the standpoint of their scientific classification. Nevertheless, since soil is the material which will be used in road construction by the road builder, some understanding must be had of the characteristics and behavior of these materials.

For this purpose, soils may be divided into two groups, which are referred to as clays and loams, since these terms are more commonly used by the layman than the more scientific designation.

It should be borne in mind that the line of demarcation between these two groups is not clearly drawn. They shade into each other, and many types will be encountered which could not readily be placed in either. The designation, however, is sufficiently definite for the general purpose of discussion of earth roads.

Clay.—The name clay is herein given to those soils which possess dense, tough and relatively impervious structure. These soils are black, yellowish, or reddish in color; are exceedingly sticky when wet, absorb water slowly, and retain it tenaciously. A road surface constructed on such a soil when once firmly compacted turns water readily, softens from the surface downward somewhat slowly, but when permeated, becomes very sticky, balling up on the wheels of vehicles in large masses; dries out slowly; is very tough when partially dry, and, during the summer months, bakes into a hard crust which is exceedingly difficult to handle with any ordinary earth-working machinery. These soils in general cannot be dragged when wet, rarely becoming sufficiently plastic to work with a drag. On the contrary, the dragging must be done after the soil is in a crumbly condition. If an attempt is made to grade a road of this type of soil in the summer months, it is found that the material can be moved only with considerable difficulty, and if it is loosened with a plow, breaks up into large pieces which are so hard that it is almost impossible to pulverize them and smooth the surface down to a passable condition.

These characteristics exist to a large extent in all soils of this general type, and present a distinct problem in earth-road construction. The degree to which the characteristics are found may vary in individual cases.

These soils also have a distinct characteristic as regards drainage. On account of the density and close texture of the soil, water permeates them but slowly, and underground drainage is much less effective than on porous types of soil. In general, tile drains along roads of this type of soil remove the water from the soil very slowly, and it is a serious question as to whether the tile is worth while so far as its effect in removing the ground water is concerned. These types of soil are also quite likely to lie in strata between which underground water will percolate. These strata often come near the surface on a public highway, and the water which is flowing between the layers will, in these places, work out to the surface causing bad mudholes commonly called "seepy" places. When such conditions are encountered, underground drainage is essential, but the tile must be laid so as to intercept the flow of water between the strata and carry it to the outlet, and thus prevent its coming to the surface of the road.

Loam.—The term loam is used herein to designate that group of soils which is of a porous and somewhat granular nature.

The loams may be yellow, reddish, brown or gray in color; in fact, many of them resemble the clays in general appearance, but all have a distinctly porous structure. Such soils absorb water readily, become more or less unstable when water-soaked, dry out rapidly, and the mud which forms on the highway is apt to be plastic and not very sticky.

A road surface of this type of soil will soften very rapidly after heavy rains, but in drying out the mud will be plastic and can be readily dragged when wet. On account of the porous nature of the soil it responds readily to underground drainage, the water percolating rapidly to the tile, and on account of the unstable condition of the soil when wet, underground drainage is of great assistance in maintaining a satisfactory roadway.

The so-called "seepy" places are also frequently encountered on this type of soil, due to underground water which works out to the surface of the road, and, as in the cases of similar places on the clay soil, underground drainage is necessary to remove the water to prevent its softening the road surface.

While these soils become hard when thoroughly dry, as is usually the case during the summer months, yet they are not as difficult to work at that time as are the clays. If a road of this type of soil is graded during the late summer months, some difficulty will be encountered in moving the material, yet it will be much easier to pulverize and get a smoothly finished surface than would be the case with clay soils.

PRINCIPLES OF DESIGN

Surface Drainage.—The one element which must determine all other features of the design of earth roads is drainage. If an earth road could be constructed in such a manner that no water would ever come onto the traveled surface, an ideal road would be obtained except for the presence of dust, but, since obviously this condition cannot be attained, every effort must be made to limit as much as possible the bad effects of the water which will come into contact with the road surface. That is to say, the first broad principle of earth-road design is to secure ample surface drainage, by giving the road a cross-section that will turn the water readily to the side ditches and then provide side

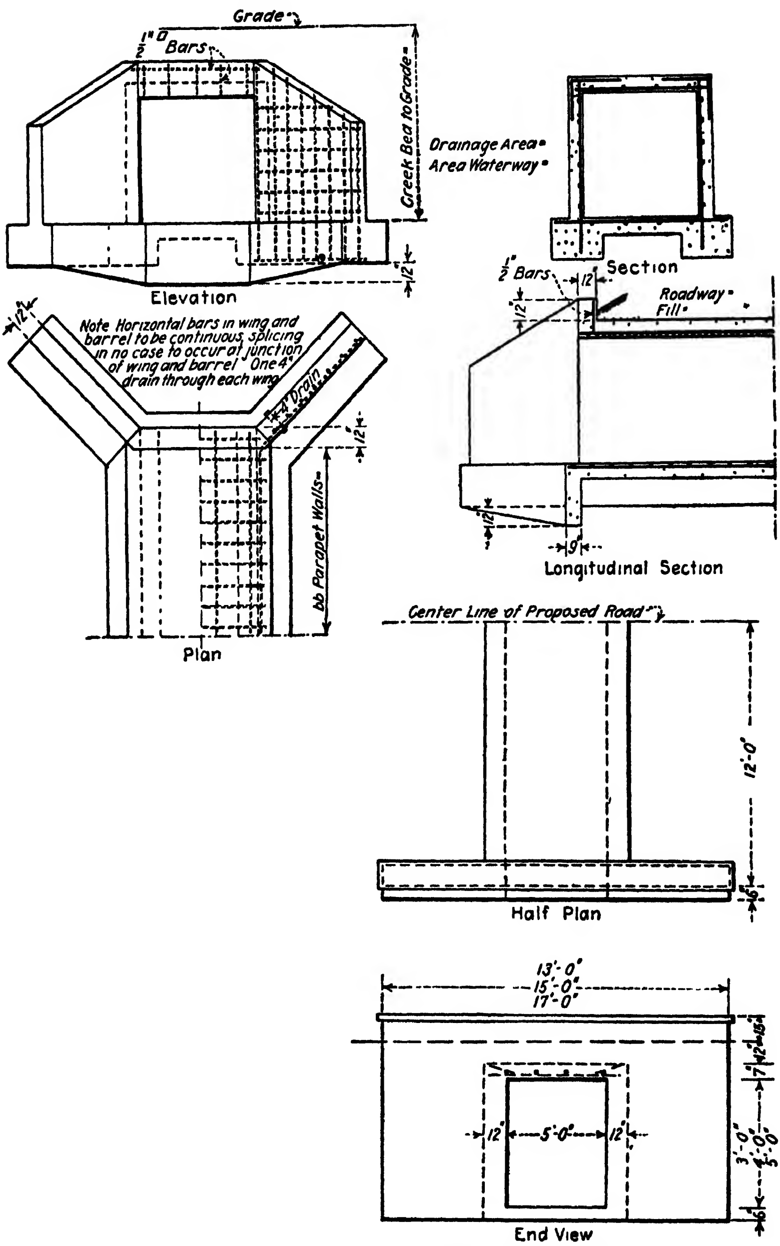


FIG. 9.—Plans for concrete box culverts.

ditches of ample capacity to carry the water quickly to some natural outlet.

So far as storm water is concerned, everything depends upon surface drainage. It is readily apparent that if underground drainage were depended upon to remove storm water, the roadway itself would become thoroughly saturated during the time when the storm water was percolating through the soil to get to the tile.

This condition could be somewhat relieved by the use of open catch-basins for taking the water to the tile, but in any case considerable time would elapse before all water was removed from the side ditches, and during this interval the roadway itself would become saturated. It is much better to depend upon surface drainage for the removal of storm water. Even with the best of side ditches, a large amount of water will soak into the road surface and at certain seasons of the year in those latitudes where the rainfall is heavy, the soil throughout a very large territory becomes thoroughly saturated with water, and even the best-designed earth road will be on the soil which carries a great deal of water. This is particularly true of those soils which have been classified under the general term "loam," and is much less true of the clay soils.

Under-drainage.—It is, therefore, desirable when the soil is a loam to provide underground drainage for removing the water from the soil after the ditches themselves have been emptied. For this purpose a line of tile may be expected to draw the water from the soil for a width of about 30 ft. each way, and one line of tile, therefore, along a public highway will effectually drain the roadway. If, however, the soil is of a dense nature such as the clays, it may be necessary to use two lines of tile, one on either side of the roadway. This can be determined only after an examination of the nature of the soil.

The depth of the tile below the surface of the ground should not be less than 4 ft., because some head is required to force the water to the tile, and it would, therefore, not drain down to its own level, and it is desirable to have at least 2 ft. of thoroughly drained earth for the road surface.

Size of Tile.—It is believed that nothing smaller than a 5-in. tile should be used along a public highway and larger sizes will often be necessary. The exact size to be used in a simple case

can readily be computed from Ponclet's formula which is as follows:

$$V = 48\sqrt{\frac{df}{L + 54d}}$$

V = velocity of flow in feet per second; d = diameter of tile in feet; L = length of line of tile in feet; and f = fall in feet in the line of tile.

Usually road tile receives water from two or three sources; (*a*) ground water, (*b*) water flowing along at top of dense strata underground, (*c*) surface water introduced at catch basins. To determine the size of tile, the quantity of water from each source must be estimated as nearly as possible, and the size of tile then determined by the above formula. When it is possible to make only approximate estimates, these should be made liberal because a road tile to be effective must remove the water rapidly. The area drained is computed from the length of the line of tile and the width it will probably drain, which will be about 60 ft.

As a general rule it is necessary to place a line of tile below the ditch in all cuts on a highway. Water will continually seep out of the banks and will keep the roadbed softened unless tile is provided to intercept it. The tile is laid in a trench at the toe of the slope from which the water flows and the trench is back-filled with broken stone or coarse gravel. Often a line of tile will be required below both ditches in cuts.

Catch Basins.—The effectiveness of the tile can be greatly increased if "blind" catch basins are used at intervals of about 500 ft. These catch basins may be made by digging down to the tile and filling the opening with coarse broken stone, broken tile, or any similar material that will form a porous channel to the tile. The top of the "blind" catch basin should be rounded up into a bee-hive shape so that it will not readily become clogged with mud or weeds. A catch basin of this type is superior to an open channel because it will not clog and will seldom need to be cleaned out.

Catch basins are particularly desirable when tile drains are used to take the ditch water from sections of the road which cannot be drained otherwise, because of topographical conditions. For such places the "blind" catch basin may be used if the quantity of water is small, but if large, an open basin should

be used. It can best be made of concrete or brick and should be covered with a grating of the bee-hive type so that it will not

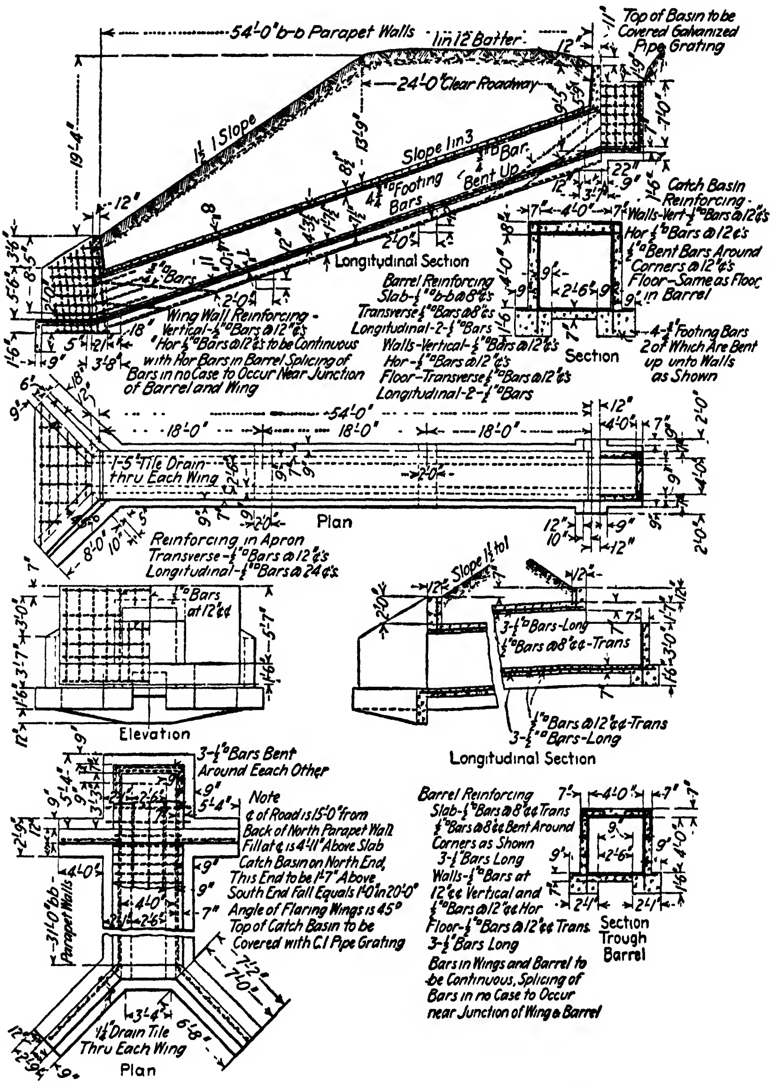


FIG. 10.—Plans for drop inlet culverts.

clog easily. A catch basin of this type will require occasional cleaning and should be large enough to permit a man to work inside it.

In no case should the water in a low place in the ditch be expected to soak through the soil to the tile. It will do so in time, but may meanwhile soften the roadway.

Tile Outlets.—The outlet of the tile should be protected by means of a masonry head wall so that the end sections cannot become accidentally displaced. It is also good practice to use bell and spigot tile for the last 10 ft., and to cement the joints. It is also important to take precautions when tile along the public highway are laid through a section of sandy soil to prevent the sand from entering the tile at the joints. The portion of the tile laid in the sandy materials should always be the bell and spigot vitrified pipe, and the joints should be cemented so that there is no possibility of water working out through the joints and removing the sand around the tile so as to permit of their displacement. And, likewise, this method of laying will prevent water from washing sand into the pipe and causing it to be displaced because of the removal of the supporting material.

Broken-stone Drains.—In localities where stone is plentiful, drains are frequently constructed by digging a trench and partially filling it with fragments of broken stone and afterward completing the filling with earth. This kind of a drain is effective for temporary purposes or for carrying water a short distance, but cannot be considered a permanent form of drain, nor is it effective if the water is to be carried more than about 100 ft.

For the protection of macadam roads during construction, or for taking a small amount of water, the broken-stone drain is frequently used, and seems to be effective. It cannot, however, be considered as a substitute for the tile drain when any appreciable amount of water must be taken care of.

CULVERTS

Purpose of Culverts.—The culvert is an important part of the drainage for a highway system, being employed to carry the water from small streams across the highway or to carry the ditch water from one side of the road to an outlet on the opposite side. No uniformity exists in the various states in regard to the distinction between "culvert" and "bridge." This discussion is limited to structures of 6-ft. span or less.

Culverts should so far as possible be constructed at such a

Table 1.[1]—Talbot's Formula For Waterways

Area of Waterway in Square Feet. $= C\sqrt[4]{(\text{Drainage Area in Acres})^3}$

C being variable according to circumstances thus:

"For steep and rocky ground *C* varies from ⅔ to 1. For rolling agricultural country subject to floods at times of melting snow, and with length of valley three or four times its, width, *C* is about ⅓, and if stream is longer in proportion to the area, decrease *C*. In districts not affected by accumulated snow, and where the length of valley is several times its width, ⅕ or ⅙ or even less may be used *C* should be increased for steep side slopes, especially if the upper part of the valley has a much greater fall than the channel of the culvert"

The following table gives ¼ roots of cubes, or the value of area of waterway for $C = 1$.

Acres	Sq. mi	$\sqrt[4]{A^3}$	Acres	Sq mi	$\sqrt[4]{A^3}$	Acres	Sq. mi	$\sqrt[4]{A^3}$	Acres	Sq mi.	$\sqrt[4]{A^3}$
1	0.002	1.0	56	0.09	20	525	0.82	110	5,500	9	639
2	0.003	1.7	58	0.09	21	550	0.86	114	6,000	9	682
3	0.005	2.3	60	0.09	22	575	0.90	117	6,500	10	724
4	0.006	2.8	65	0.10	23	600	0.94	121	7,000	11	765
5	0.008	3.3	70	0.11	24	625	0.98	125	7,500	12	806
6	0.009	3.8	75	0.12	26	650	1.02	129	8,000	13	846
7	0.011	4.3	80	0.13	27	675	1.05	132	8,500	13	885
8	0.013	4.8	85	0.13	28	700	1.09	136	9,000	14	924
9	0.014	5.2	90	0.14	29	750	1.17	143	9,500	15	962
10	0.016	5.6	95	0.15	30	800	1.25	150	10,000	16	1,000
11	0.017	6.0	100	0.16	32	850	1.33	157	10,500	16	1,037
12	0.019	6.4	105	0.16	33	900	1.41	164	11,000	17	1,074
13	0.020	6.8	110	0.17	34	950	1.48	171	12,000	19	1,147
14	0.022	7.2	120	0.19	36	1,000	1.56	178	13,000	20	1,217
15	0.023	7.6	130	0.20	38	1,050	1.64	184	14,000	22	1,287
16	0.025	8.0	140	0.22	41	1,100	1.72	191	15,000	23	1,355
17	0.027	8.4	150	0.23	43	1,150	1.80	197	16,000	25	1,422
18	0.028	8.7	160	0.25	45	1,200	1.88	204	17,000	27	1,489
19	0.030	9.1	170	0.27	47	1,250	1.95	210	18,000	28	1,554
20	0.031	9.5	180	0.28	49	1,300	2.03	216	19,000	30	1,618
21	0.033	9.8	190	0.29	51	1,350	2.1	223	20,000	31	1,682
22	0.034	10.2	200	0.31	53	1,400	2.2	229	22,000	34	1,806
23	0.036	10.5	210	0.33	55	1,500	2.3	241	24,000	38	1,928
24	0.037	10.8	220	0.34	57	1,600	2.5	253	26,000	41	2,048
25	0.039	11.2	230	0.36	59	1,700	2.7	265	28,000	44	2,165
26	0.041	11.5	240	0.38	61	1,800	2.8	276	30,000	47	2,280
27	0.042	11.8	250	0.39	63	1,900	3.0	288	35,000	55	2,559
28	0.044	12.2	260	0.41	65	2,000	3.1	299	40,000	62	2,828
29	0.045	12.5	270	0.42	67	2,100	3.3	310	45,000	70	3,090
30	0.047	12.8	280	0.44	68	2,200	3.4	321	50,000	78	3,344
32	0.05	13.5	290	0.45	70	2,300	3.6	332	55,000	86	3,591
34	0.05	14.1	300	0.47	72	2,400	3.8	343	60,000	94	3,834
36	0.06	14.7	320	0.50	76	2,600	4.1	364	65,000	102	4,071
38	0.06	15.3	340	0.53	79	2,800	4.4	385	70,000	109	4,304
40	0.06	15.9	360	0.56	83	3,000	4.7	405	80,000	125	4,757
42	0.07	16.5	380	0.59	86	3,200	5.0	425	90,000	141	5,196
44	0.07	17.1	400	0.63	89	3,400	5.3	445	100,000	156	5,623
46	0.07	17.7	420	0.66	93	3,600	5.6	465	120,000	188	6,447
48	0.08	18.2	440	0.69	96	3,800	5.9	484	140,000	219	7,238
50	0.08	18.8	460	0.72	99	4,000	6.2	503	160,000	250	8,000
52	0.08	19.4	480	0.75	103	4,500	7.0	549	180,000	281	8,739
54	0.08	19.9	500	0.78	106	5,000	7.8	595	200,000	312	9,457

[1] Office and field practice of Iowa Highway Commission.

height that they will not make it necessary to raise the profile of the road in order to carry the roadway over the culvert. In some instances in very flat sections of road this is not possible and it becomes necessary to raise the road grade at the culvert. At such places the slope should be carried a sufficient distance each side of the culvert to insure an easy-riding crossing. Abrupt raises at culverts are uncomfortable for traffic and often are dangerous.

The culvert should be fitted to the traveled way so as to be practically unnoticeable until the traveler is close to it. It should also fit the stream so that the water will flow through with the least disturbance of its natural course consistent with reasonable economy.

The bottom of the culvert should not be placed too low, because of the tendency for the stream above the culvert to erode to the level of the culvert floor. If the stream has eroded a deep channel, the culvert proper may be placed at the level of the existing stream bed so that the lower end will discharge without causing undue erosion, but the upper end may be provided with a drop inlet, the top of which is several feet above the old stream bed. The stream bed above the culvert will gradually fill up to the top of the drop inlet, and thus valuable land will be reclaimed.

The size of culvert is best determined by estimating the drainage area contributory to it, and then applying one of the well-known formulas to determine the area of waterway. One of these formulas is shown in Table 1:

TYPES OF CULVERTS

Reinforced Concrete.—Reinforced concrete is a desirable material for culverts because the form of the culvert can be readily adapted to the site. The materials are obtainable in almost every locality, and can readily be transported to the site because they can be carried in small units. The resultant structure is proof against injury from the elements, and the strength of the culvert can be adapted to the location. Figs. 9 and 10 show a few typical plans for concrete culverts.

Pipe Culverts.—Culverts are made of clay pipe, cast-iron pipe, concrete pipe, and, to a limited extent, from steel pipe riveted into appropriate lengths. The load on a pipe in a ditch is made

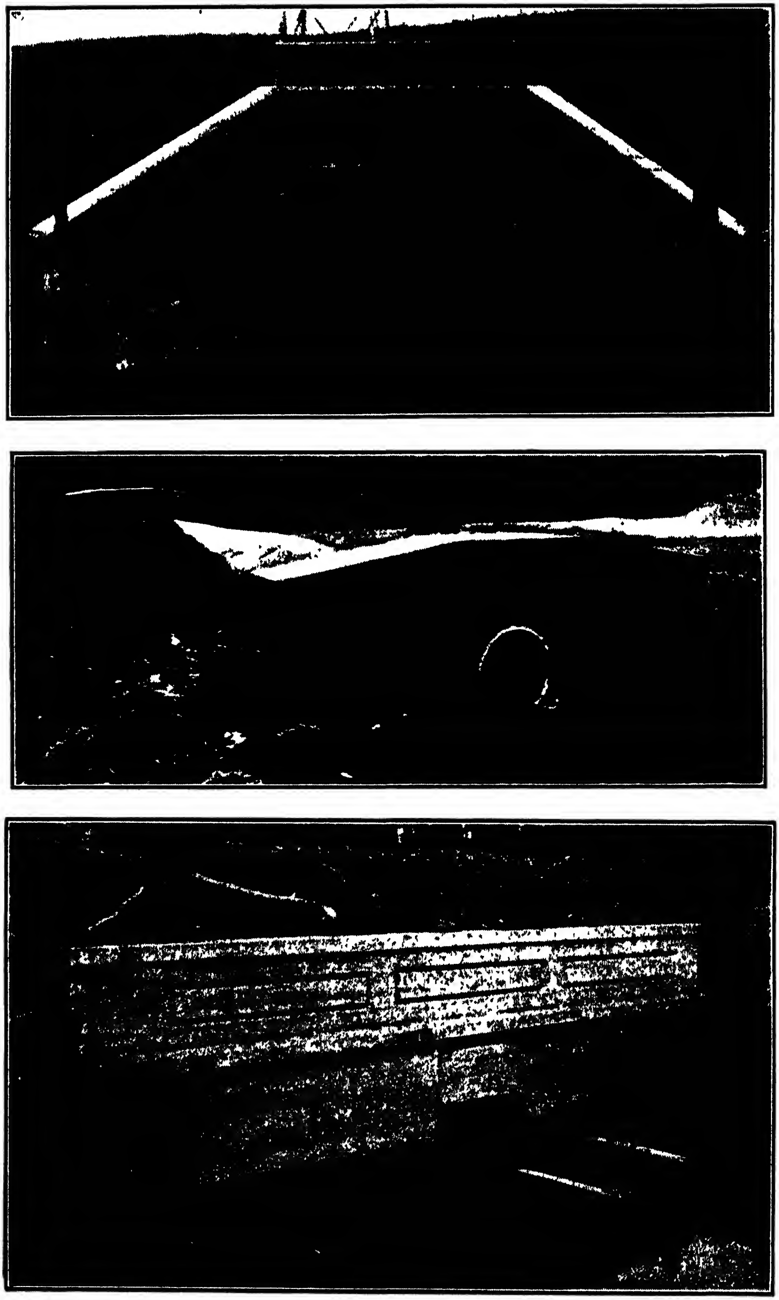


FIG. 12.—Views of completed culverts.

and type of wheel, but for most cases an area of 12 by 24 in. is about right. The pressure is then assumed to distribute on 45° lines from this area and the unit pressure on the culvert at the existing depth is calculated. This undoubtedly gives too low values for shallow fills, but the culverts designed on the above assumption are satisfactory.

This emphasizes the necessity for care in the use of sectional pipe, especially under shallow fills. The pipe should be carefully bedded and concrete should be employed for bedding except on the most stable soil. The joints should be close and should be filled with cement mortar. The back filling should be well tamped, especially at the sides of the pipe.

Pipe culverts are preferably provided with adequate head walls, to retain the fill and to prevent under-cutting or other harmful erosion. The head walls should extend at least 2 ft. below the barrel of the culvert, and the top should be 1 ft. to 18 in. above the top of the barrel. The wings to the head wall are designed to fit the slope of the fill, assuming a slope of 2 on 1.

Figure 11 shows some designs of pipe culverts and headwalls, and Fig. 12 shows some views of completed culverts.

CROSS-SECTIONS

For convenience in discussion, the cross-section of the road may be considered as made up of three parts: the traveled way; the ditch; and the back slope and berm.

Traveled Way.—The traveled way, as its name indicates, is that portion of the roadway that is used by traffic. It should have a shape that will insure its being well drained, that is, it should be well rounded up or "crowned."

The comfort and safety of those who travel must also be considered in designing the cross-section.

If the cross-slope of the traveled way is excessive, it will be uncomfortable to travel, and, when wet and consequently slippery, it will be dangerous as well. The exact amount of cross-slope that may be used is a matter that has been determined by experience, and it is believed that an average of 1 in. per foot of width is about the maximum that is permissible. For convenience in construction, the shape of the traveled way may be an arc of a circle or a parabola. It has frequently been said that the cross-slope should be greater on hills than in level country, the argument being that if the cross-slope is not made

greater, storm water will have a tendency to follow the wheel tracks down the hill rather than run crosswise to the side ditches. While there is reason to this argument, still, from the standpoint of comfort and safety, it is undesirable to have any greater cross-slope on hillsides than in level country. The tendency to slide is greater on hillsides than in level country, and the results of skidding or sliding to the ditch are much more aggravating. For that reason, it is believed to be undesirable to use a much greater cross-slope on hillsides than is used in level country.

If there is any probability that the earth road may at some future time be surfaced with some hard material, then the shape of the traveled way should be such as to render it easily convertible for the hard-road cross-section. If it is so designed that when the hard surface is built, the only necessary earth work will be that which is done in flattening the cross-slope to an amount which is desirable for the hard surface, the most economical design has been adopted.

The width of the traveled way is also a matter which deserves consideration. If the traffic consists of a few vehicles daily, then a comparatively narrow roadway is all that is necessary, but, if the road is subjected to mixed traffic some of which moves at relatively high speed, which is the common condition encountered on most main traveled highways, then the section should be wide enough to accommodate readily this mixed traffic, and it is believed that 24 ft. is a minimum width, although on some secondary roads a width of 20 ft. might be used. Undoubtedly other cases are encountered where the traffic is sufficient in amount to necessitate a width greater than 24 ft.

Ditches.—The portion of the road outside of the traveled way is utilized for ditches and the berms along fences. The ditch should be of ample capacity, and, if it is assumed that all surface water is carried in these ditches, the size or capacity necessarily will vary with the slope. This should never be less than $\frac{1}{10}$ per cent. if the water is to flow away before it injures the road. As the slope of the ditch increases, its depth may be decreased. It is not convenient in road work to change the size of the ditch constantly, and, consequently, two or three sections are usually adopted which will fit a variety of conditions. Fig. 13 shows sections that may be used on various grades.

It is important that the slope from the shoulder to the ditch should be flat enough to permit a vehicle to run to the bottom of

the ditch in case of accident without danger of over-turning, and this is possible on a slope of 2½ on 1. The slope of the back of the ditch may be whatever the natural soil will stand, but should be uniform. It will usually be about 1½ on 1. The ditch may have the V section, or may have the trapezoidal section. The former is the easier to build, but the latter has greater capacity.

The Berm.—The portion of the road between the ditch and the fence or property line will vary in width, being least where

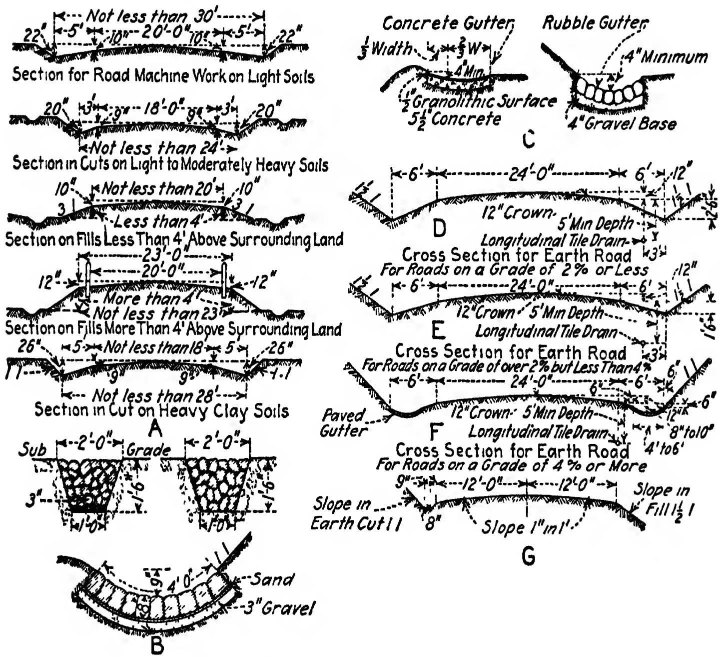


Fig. 13.—Cross sections for earth roads.

cuts have been made. The only necessary requirement is that it be sufficient to obviate the possibility of endangering the stability of the fences. As a rule this space is an unkept weed or brush patch on the road, but eventually it will be made use of in some manner. Probably on a great many roads it will be planted to useful trees and shrubs or be given over to ornamental plants and trees.

GRADES FOR EARTH ROADS

In discussing the principles of selecting grades for earth roads, the fact that the road may be surfaced at some future time must

be taken into account. It cannot be foretold what class of hard surface will be used in many cases, but usually it is possible to determine about the character of the surface from the classes of material available. For convenience in discussing the various grades, such terms as *maximum grade*, *average grade*, and *ruling grade* are often used. These terms have no exact or generally accepted meaning, and merely serve to facilitate discussing the various conditions encountered.

Maximum Grade.—The maximum permissible grade is that which can be allowed without making it necessary to reduce the ordinary size of load hauled over the road. It is well known that a team can increase its pulling power for short periods of time to two or three times that which it would be expected to exert continuously.

Theoretically, the increased pull required on grades is 20 lb. per ton for each per cent. increase in grade, and this has been proven by experiment to be true in practice. If, then, a team is loaded with the amount it can haul readily on level road, having a surface offering a resistance of 100 lb. per ton, and it is assumed that the team can for a short time double its pull, it would be possible to haul the load up a 5 per cent. grade. For earth roads, in good condition, the tractive resistance will be about 106 lb. per ton, and if the hauling is done entirely on earth roads, the maximum grade could be about 6 per cent. without necessitating a reduction in the size of the load. If the hill is surfaced as with a material offering a tractive resistance of 60 lb. per ton, the capacity of the team would be increased so that the maximum grade could be 8 per cent. As a matter of fact, grades of 8 per cent. and 10 per cent. are not infrequently encountered on earth roads, and do not necessitate reducing the size of loads hauled.

If the entire road is to be surfaced at some later time with material offering a tractive resistance of 60 lb. per ton, and it is assumed as before that the team can double its pulling power for short periods of time, then the ideal maximum grade would be 3 per cent.

As a matter of practice, many highway engineers take 6 per cent. as the maximum grade to be obtained, permitting steeper grades only when topographical conditions necessitate.

Ruling or Average Grades.—In determining grades on long sections of road in rolling country, there will be many hills

below the maximum adopted which may easily be reduced. Obviously it is uneconomical to spend money to reduce a grade on one hill from 3 per cent. to 2½ per cent. when near it is another hill that cannot economically be reduced below 3 per cent. It is customary to select some ruling grade for all hills below the maximum grade, except, of course, those already below the ruling grade selected. There is no rule by which this average grade can be determined, but when the maximum is 6 per cent. the ruling grade is usually selected at about the grade where erosion becomes a factor in the maintenance of the ditches.

Minimum Grades.—An earth road or any kind of surfaced road may have a level profile, the ditches being sloped for drainage. The cross-slope insures drainage for the surface of the road.

Undulating Roads.—When roads are in rolling country, many slight grades are encountered, and, as a general rule, no economy results from removing or reducing them. Experiments have shown that the travel downhill compensates for the travel uphill, so long as the grade is below that at which the vehicle would coast. On earth roads, then, if no grade of over 5 per cent. exists, the travel downhill will compensate for the travel uphill, and the average tractive effort for a round trip will be no greater than on a level road.

Safety Considerations.—Steep grades, sharp curves and knolls that obstruct the view ahead should be avoided in the interest of safety. There should always be a clear view ahead for at least 250 ft. and if a curve exists on a hill, the grade should be flattened around the curve if possible so as to permit a quick stop in case of emergency.

Balancing Quantities.—The amount of material removed in excavation should all be used in the fills, that is, the grade line should "balance." It is well known that most soils removed in excavation will occupy less room in embankment after settlement. The amount of this shrinkage depends upon the kind and condition of soil, the method of placing, and the depth of the fill. For fills under 2 ft. in depth, 20 per cent. is about an average allowance for shrinkage. For fills over 2 ft. in depth the allowance may be reduced to 15 per cent. Instances have been encountered where the shrinkage amounted to as much as 30 per cent. in fills less than 6 ft. deep.

CHAPTER IV

THE CONSTRUCTION AND MAINTENANCE OF EARTH ROADS

GRADE REDUCTION

When in accordance with the principles of design already discussed it becomes desirable to reduce the grade on a section of road, certain preliminary work should first be completed. If there are weeds, brush or trees on the portion of the road to be graded, these should be cut away or grubbed out and the resulting débris burned. It is especially undesirable to leave organic matter under a fill because it will decay and cause unequal settlement. It may also cause under-cutting from water that works under the fill where it is porous from the decay of organic matter.

If fills are made on side hills where the cross-slope is steeper than 4 on 1, provision should be made to insure a bond between the new fill and the old ground. If the existing soil is porous and the slope does not exceed 3 on 1, this can be accomplished by plowing a series of furrows about a foot apart parallel to the center line of the fill. For dense soils or slopes greater than 3 on 1, the area to be covered by the fill should be graded to a series of horizontal benches about 4 ft. wide. After this preparation is completed the fill may be placed in a series of horizontal layers not over 2 ft. thick.

When the fill is constructed on a road that has a cross-slope flatter than 4 on 1, the new material may be placed without special preparation of the site except to remove the vegetable matter. For fills of this class it is undoubtedly advantageous to place the fill material in layers not exceeding 2 ft. in thickness. The teams and scrapers will compact the material as they travel over it, and the fill that is built up will not settle excessively. Some engineers require that each layer shall be rolled before the succeeding layer is placed, but it is doubtful if there is enough benefit obtained from the rolling to compensate for the cost. If fills less than about 2 or 3 ft. in height are to be con-

structed and a hard surface of some kind is to be built immediately, it is probably advisable to place the fill in layers of 6 or 8 in. and roll each thoroughly. This does not apply to earth-road building, however.

In general, it may be said that satisfactory practice for earth roads is to permit the fill to be placed without restrictions as to the thickness of the layers, and without rolling. Suitable provision must be made in any case for possible shrinkage.

Side Slope in Cuts.—The side of cuts should be trimmed to a slope suitable to the soil. Some soils will stand on a much steeper slope than others, and the side slope of the cut should be as nearly as possible that at which the soil will stand without sliding. For loam, 1½ on 1 will generally prove satisfactory.

FIG. 14.—The elevating grader drawn by mules.

For most of the clays the slope may be 1 on 1, and for some peculiar soils, such as loess, the sides of cuts will stand better if vertical than if they are on a slope. For the sake of appearances, the side slopes are neatly hand-trimmed to the slope that has been determined upon.

Side Slopes for Fills.—Since the fill material is of necessity loose when placed, the side slopes will shape themselves to the angle of repose of the material in the condition in which it is deposited. This slope will invariably flatten out as the fill settles, and as the material becomes saturated with water. It is good practice to employ a side slope of 2 on 1 for fills, but here again some variation is permissible if the soil exhibits special

or peculiar characteristics. The side slopes should be neatly shaped so as to present a good appearance, and the filling should be carried out against head walls and abutments to the final slope desired.

Protection of Slopes.—A considerable amount of maintenance work on side slopes is obviated if they are seeded with some sort of hardy grass having strong roots. There is some type of

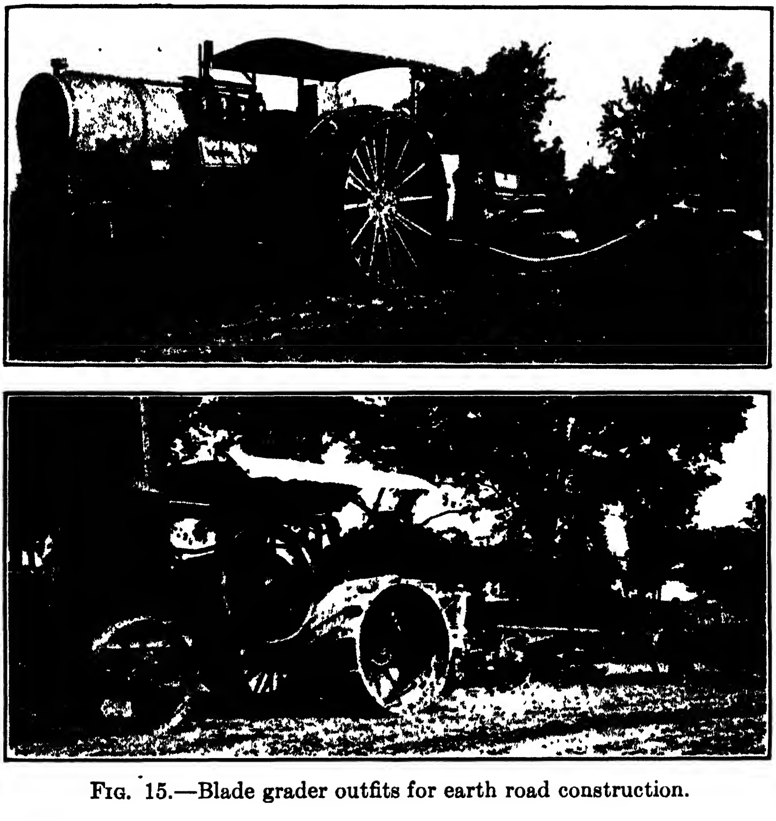


FIG. 15.—Blade grader outfits for earth road construction.

grass suitable for this purpose that can be grown successfully in each locality, and the species best adapted to the locality can be ascertained. For the Middle West, Hungarian Brome grass is best for slopes facing the north, east or west, but western wheat grass is better for slopes facing the south.

Overhaul.—The price for grading is commonly based on a specified length of haul, and if any part of the material is hauled a greater distance, the excess haul is known as "overhaul" and is

paid for at a higher rate than that for earth which is moved only the specified distance or less. The proper length of the "free haul," as it is called, *i.e.*, the length of haul for the contract price, has been the subject of considerable discussion, most of which has reached no definite conclusion. Undoubtedly overhaul provisions are desirable when a part of the fill material or extra excavated material must be moved appreciably further than the remainder and large portion of the material. When such a condition exists, the average haul for the larger portion of the excavation can be used as a basis for payment, with an overhaul provision to take care of the balance.

FIG. 16.—The leveler employed for earth road construction.

If, on the other hand, the excavated material will all move substantially the same distance, no matter what that distance is, no overhaul provision is necessary.

It is, therefore, undesirable to fix any free-haul limit for general application. If material moves less than 500 ft., there would usually be no overhaul provision, and, on the contrary, the free-haul distance may be as great as 2,000 ft.

Shrinkage.—Most earth will, when deposited, finally compact into a smaller space than it occupied before being excavated, and fills will generally settle slowly for some months after they are placed. The amount of shrinkage will depend upon the moisture content of the earth during and immediately after it is moved, the manner in which it is moved, the depth of the fill, and the character of the soil. Shallow fills compact more than deep ones, wet soil more than dry, and porous soil compacts more than dense soil. If the material is handled in small units, it will shrink

less after the fill is completed than if it were handled in large units. That is, slip-scraper work will shrink less than work handled by a 2-yd. dump car.

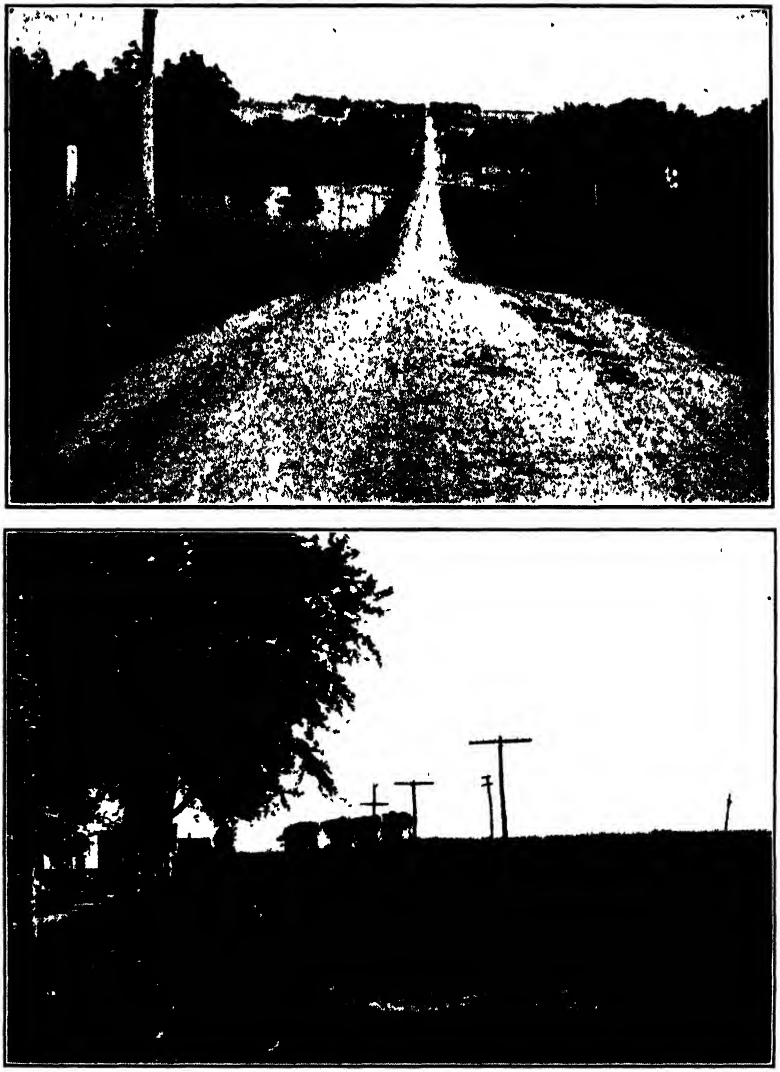


FIG. 17.—Properly constructed and maintained earth roads.

No reliable general rule for shrinkage can be laid down that will fit all conditions, and the shrinkage for moderate or heavy

fills is best estimated after an examination of the material to be moved. The shrinkage will seldom be less than 10 per cent. (although there may be none at all in rare cases) and not often more than 30 per cent. For approximate estimates of shrinkage 15 per cent. may be used for fills over 2 ft. deep, and 20 per cent. for fills less than 2 ft. deep.

Computing Quantities.—Payment for grading is ordinarily based on measurement in excavation, the quantities being computed by the average end area method. This applies to borrow excavation as well as to excavation of roadway. In exceptional cases payment is made on a basis of quantities in embankments. This is a desirable method where the material for filling must be obtained from scattered borrow pits, or from borrow pits that are very irregular and, therefore, difficult to measure. In determining overhaul, the following method is satisfactory, and is believed to be equitable: Determine the distance between the center of mass of the material to be excavated and the center of mass of the fill. Subtract from this the free-haul distance. Multiply the distance in feet thus obtained by the total quantity of excavation in cubic yards, and the result is the cubic yards-feet of overhaul. This can readily be reduced to the proper unit for payment. A typical case would be where payment for overhaul is to be at the rate of ½ ct. per cubic yard for each 100 ft. of overhaul. The cubic yards-feet of overhaul would be divided by 100 and multiplied by $0.005 to obtain the overhaul allowance.

Methods of Grading.—Many kinds of equipment are used for grade-reduction work in highway construction just as is true of any other kind of grading. Each has its particular field of usefulness.

Steam-shovel Excavation.—Where heavy grading is being done so that an outfit can be used continuously for a long time without frequent costly moves, the steam shovel is economical. A standard railroad outfit would be employed for very heavy work, and the materials would be handled in dump cars on the industrial railway. For lighter work the traction type of shovel would be more satisfactory, and the earth would be hauled in horse-drawn dump wagons.

Elevating Grader and Dump Wagons.—If the cuts are relatively shallow, the elevating grader would be utilized for loading the dump wagons.

Wheel or Fresno Scrapers.—If the excavation is light and outfits must move frequently, the wheel or Fresno scraper may be used. If the topography is unsuited for the elevating grader, the wheel or Fresno scrapers would also be most economical.

Costs.—The cost of moving earth for a free haul not exceeding 500 ft. will vary from 17 cts. to 25 cts. per cubic yard in prairie country, and from 20 cts. to 50 cts. per cubic yard in rough country with heavy soils, depending, as would be expected, on a variety of conditions.

Fig. 18.—The steam shovel employed for highway construction.

RESHAPING AND LIGHT GRADE REDUCTION

Elevating Grader Work.—If a road is designed in accordance with the principles already set forth, particularly as regards cross-section, the elevating grader can be used to good advantage in the construction.

In general, the work to be done consists in rounding up the traveled portions of the road with material obtained from the side ditches. The best results will be obtained with this outfit in flat country or slightly rolling country where sections a mile

or more in length can be constructed at one time, thus obviating frequent turning of the outfit.

Before the grading is started, the portion of the right-of-way upon which work is to be done should be cleared of grass, weeds, and brush. This may be accomplished by cutting off the growth and raking it into piles and burning. When only a small amount of growth exists, it is sometimes cut off with the blade grader and pushed off the portion of the road upon which work is to be done.

Classes of Road Work for Elevating Grader.—There are the three following classes of roads encountered where the elevating grader has proven satisfactory:

1. Roads practically level where the new grade line is parallel to the profile on the old road, there being only a few knolls to be removed.

2. Roads on which there are a succession of knolls and consequently a succession of cuts and fills, most of which do not exceed about 2 ft. in depth.

3. Roads where extensive grade-reduction work must be done.

Grader Outfits.—The outfit necessary for roads of class 1 consists of the elevating grader drawn by six or eight teams or by a tractor, a blade grader, a few slips or wheelers, a heavy disc harrow, a heavy straight-tooth harrow, and a split-log or plank drag. If a roller is also available a better road can be constructed than is possible without it. For roads of class 2, a number of dump wagons are also necessary.

Construction Methods.—In starting the construction, the first cut is taken at the shoulder line, and the material thus removed is deposited near the shoulder line of the opposite side of the road, but in the roadway.

Stakes are set for the first cut so that the driver can follow them conveniently. If the outfit is horse-drawn, the stakes are set so that the tongue of the elevating grader will follow them. If the grader is drawn by a tractor, the stakes are set so that the front wheel on the steering side will follow them. The exact distance of these stakes from the line of the cut will vary somewhat with the type of elevating grader used and must be determined before the stakes are set.

The first cut is a light one and usually one horse of the lead team follows this first furrow and thereby guides the grader in making the succeeding cut. If the grader is drawn by a

tıactor, a side hitch is used so that the tractor will travel on the "land" side.

On roads of class 1, the successive rounds of the elevating grader are made without reference to the slight knolls that occur; and the material deposited on the roadway on top of the knolls is hauled away by slips or wheelers while the elevating grader is completing its round. A suitable adjustment of the working forces can be made so that the slips or wheelers can keep up with the grader.

On roads of class 2, teams with dump wagons follow the elevating grader, loading where cuts are to be made and dumping the materials in the fills, the elevating grader continuing its rounds and depositing directly on the road in the low places. Here again a suitable adjustment of working forces must be made so that the elevating grader will not have to wait for the wagons. It is more economical to construct a mile or more of road at a time than it is to turn the elevating grader constantly, as would be necessary if each cut were completed by itself.

As the elevating grader makes successive rounds it gets farther away from the center of the road, and, consequently, when it is at the deepest part of the ditch where the heaviest cutting is being done, the earth is deposited in the middle of the road, where the greatest filling is necessary to give the crown.

The material deposited on the roadway will consist of many large lumps as well as of sods and fine material. To work this material down to a surface that can be traveled, the clods and sods must be broken up with a disk harrow until small enough to form a satisfactory surface. Often the sods and weeds are collected by harrowing with a stiff-tooth harrow and thrown out with pitchforks.

To bring the surface to its final shape a few rounds must be made with a blade grader. Then, after the first rain, the surface is smoothed with a road drag, and, when partially dry, rolled. Constant dragging is necessary during the first year to keep the road in shape, while it is becoming compacted by traffic.

Cost Data.—The cost of constructing earth roads by this method varies from about $100 per mile for class 1 roads, to $250 per mile for class 2. As an average of the work done by a well-organized outfit, $150 per mile may be taken.

The cost of the elevating grader outfit is from $4,000 to $5,000, depending upon its size and the number of accessories

used. To secure economical construction requires experienced supervision and proper working conditions, but when these are had, the use of the elevating grader is one of the most economical methods of earth-road construction. In general, it is not suitable for any unit smaller than a county, because of the cost of the outfit and the mileage of work that must be done yearly to make it pay.

Blade-grader Work.—When the blade grader is used for shaping the cross-section, it is necessary to complete all grade-reduction work before beginning the shaping. The grade-reduction work is commonly performed with the wheel scraper, Fresno scraper, or with the elevating grader as described in the preceding section. The latter is not common, however, because, if the elevating grader is available at all, it is generally employed to the exclusion of the blade grader.

Having brought the road to the adopted profile, the blade grader is used to shape the cross-section. The first cut is made near the shoulder line and succeeding cuts farther out in the ditch, and the material thus excavated is dragged to the middle portion of the road and used to round up the roadway. Two graders, hitched together, are sometimes drawn by one tractor, thus increasing the speed with which the work can be completed.

The road is finally smoothed with the drag and is maintained by frequent dragging until thoroughly compacted, and later by less frequent dragging.

The cost of work done with the blade grader does not differ greatly from the cost of similar work done with the elevating grader, but the blade grader is not adapted to as many conditions as the elevating grader is.

The blade-grader outfits, consisting of a tractor and a heavy grader, cost from $3,000 to $3,500.

METHODS OF MAINTENANCE

The maintenance of the earth road must be carried on throughout the year, because, in the very nature of the case, it is a class of road that will deteriorate steadily and rapidly otherwise.

The principal part of the maintenance work will be most readily accomplished by means of the split-log or some similar form of drag. Fig. 19 shows some satisfactory types of drag. In addition, some blade-grader work will be needed and there

will be some miscellaneous work such as cleaning out culverts, cutting weeds, and general shaping of ditches and the slopes of cuts and fills.

Use of the Drag.[1]—The successful operation of a drag involves two principles, which, when thoroughly understood and intelligently applied, make road working with this implement very simple. The first concerns the length and position of the hitch, while the second deals with the position of the driver on the drag. Each influences the other to a large extent, and successful manipulation of the drag is dependent upon an understanding of both of them.

For ordinary purposes the clevis should be fastened far enough toward the blade end of the chain to force the unloaded drag to follow the team at an angle of 45°. This will cause the earth to move along the face of the drag smoothly and will give comparatively light draft to the team, provided the driver rides in the line of draft. Sometimes, however, conditions are met which require special treatment, and in a rolling country such conditions are not infrequent. Often a flat place several rods in length, or a seepy spot, needs special attention.

The distance from the drag at which the team is hitched affects the depth of the cutting. Shortening the chain tends to lift the front slab from the ground; a longer hitch causes the blade to cut more deeply. The length of hitch may be regulated by lengthening and shortening the chain at the end which runs through the hole in the blade end of the drag.

If small weeds are to be cut or a furrow of earth is to be moved, the doubletree should be attached rather close to the ditch end of the drag. The drag will now move nearly ditch end foremost, and the driver should stand with one foot on the extreme forward end of the front slab. This will swing the drag back to the proper angle and will cause the blade to plow. This hitch requires slow and careful driving in order to prevent the drag from tipping forward. If the blade should plow too deeply, as it may do in a wet spot, the driver should shift his weight toward the back slab.

If straw and weeds clog the blade, they can usually be removed if the driver shifts his weight to a point as far as possible from the ditch or blade end. Similarly, if he steps quickly away

[1] Abstract from *Bulletin* No. 597, U. S. Department of Agriculture.

from the ditch end, the load of earth may be dropped into a low place or mudhole.

Usually two horses are enough to pull a drag over an ordinary earth road. When four horses are used, they should be hitched to the drag by means of a four-horse evener. The team should be driven with one horse on either side of the right-hand wheel track or rut, the full length of the portion to be dragged, and the return made over the other half of the roadway.

The object of such treatment is to move the earth toward the center of the roadway and to raise it gradually above the surface level. While this is being accomplished, all mudholes and ruts will be filled into which traffic will pack the fresh earth.

When to Use a Drag.—The drag does the best work when the soil is moist, but not sticky. The earth then moves freely along the faces of the slabs. If the roadway is very badly rutted and full of holes, it would be well to use the drag once, when the ground is slushy. This treatment is particularly applicable before a cold spell in winter when it is possible to have a roadway freeze smooth.

A smooth road surface is secured by this method. Clay, when mixed with water and thoroughly worked, becomes remarkably tough and impervious to water. If compacted in this condition it becomes extremely hard.

Another valuable result of dragging is the reduction of dust, for the particles of clay cohere so tenaciously that there is but little wear when the surface is smooth. Dust on an earth road is due to the breaking up under traffic of the frayed and upturned edges or ruts and hoof prints. If the surface is smoothed after each rain and the road dries hard and even, no edges are exposed to crushing and the only dust which forms is that due to actual wear of the road surface.

There are so many influences at work and conditions are so varied in different localities that it is quite impossible to lay down a general rule for the number of treatments needed to keep a road in good condition. A tough clay or a stiff sandy clay will resist the action of wheels and hoofs for a longer period than a loam, other things being equal. Certain sections of a roadway will require more attention than others because of steep grades, exposure to hillside wash, etc. The best guide in meeting these conditions is the knowledge and experience gained while dragging the roadway.

There is one condition, however, in which special treatment should be given to a road. Clay hills under persistent dragging frequently become too high in the center. To correct this, it is best to drag the earth toward the center of the road twice and away from it once.

Use of a Drag on Rocky or Gravelly Roads.—In soils full of loose stones, or even small boulders, the drag has done good service. The loose stones are drawn into a windrow down the center of the road while the earth is deposited around the boulders in such a way that the surface is leveled. The loose stones in the center of the road should, of course, be removed. Where there is a large proportion of small stones or gravel, the drag will keep down the inequalities in the surface.

General Maintenance Work.—Even when the drag is used properly the road will gradually become too flat and the ditches will fill up with material carried off the roadway by storm water. When this condition reaches the stage where it becomes a menace to the drainage, the blade grader is used to draw in the material from the ditch and restore the crown to the road.

The earth and weeds that accumulate at the ends of culverts must be removed periodically, and the weeds and grass along the fences must be cut once or twice a year.

Drainage channels and tile will require occasional attention to keep them in good working condition.

Cost of Earth-road Maintenance.—Little data bearing on the cost of earth-road maintenance has been published, but from that which is available, it is believed that the cost of adequate earth-road maintenance is from $30 to $50 per mile per year.

MACHINERY USED FOR EARTH-ROAD WORK

Picks, Mattocks.—These tools are used for grubbing, dressing up earth work, and for similar familiar purposes. They are used so commonly and are so well known that no comment is necessary.

Shovels, Spades.—For moving loose earth or slightly tramped material, the ordinary No. 2 shovel is commonly used. It is not an economical tool for digging hard earth, and either the ordinary flat spade or the solid back tile spade should be used for that purpose.

For handling broken stone, sand, gravel, and similar mate-

rials, the No. 1 ore shovel is used. It is slightly larger than the No. 2 shovel, and turns up a little more at the sides and does not spill loose material as readily as does the ordinary No. 2 shovel. Sometimes a small scoop shovel is used for handling sand and gravel, and it is satisfactory if the material is loosely piled and is on a good surface for shoveling.

Plows.—The plow used in highway construction is subjected to very severe service and must be strongly made. It should have a long iron-shod beam with a shoe and the width should not exceed 10 in. It should be strong enough to stand up when drawn by a tractor.

Rooter Plows.—If old gravel roads or roads containing stony material or hard-baked earth are to be loosened, the rooter plow is the most suitable. It is heavy and often has a cast beam. It has a point, sharpened on both ends, for breaking the soil, and can be reversed or the working length adjusted.

Harrows.—For breaking up the sods and large lumps of soil after a road has been graded, a disc harrow heavily loaded is most commonly used, but a stiff-tooth iron harrow may be satisfactory if the soil is not too throughly dried out.

If the harrow is to be used for crushed stone or gravel, then a stiff-tooth harrow, having a weight of 10 to 15 lb. per tooth, is best. It should be strongly built and not so large as to require more than one team. A harrow about 4 ft. square with a corner hitch is well adapted for this work.

Slip Scrapers.—Slip scrapers are suitable for moving rough materials, especially earth, if the haul does not exceed about 100 ft. They are well suited to small work since they require no loader other than the driver, and no dumper. The slip scraper may be used in connection with an inclined chute for loading crushed stone or gravel from a storage pile into wagons.

Fresno Scrapers.—The Fresno scraper is used widely in the Pacific Coast States, and, to a less degree, elsewhere for the same purposes as the slip scraper. It is more efficient than the slip scraper, and is suitable for hauls up to about 500 ft.

Wheel Scrapers.—The wheel scraper is used for general earth-moving work where the haul is 200 ft. or more, but is not efficient if the haul exceeds about 1,000 ft. It is made in several sizes ranging in capacity from about 5 cu. ft. to 16 cu. ft. The larger size is preferable on heavy work, as a "snap" team must be employed in loading in any case. A loader and a dumper must

always be employed and usually the material to be moved must be loosened with a plow before it can be loaded. The common practice is to plow two furrows on one side of the cut, then wheel them out while two furrows are being plowed at another place in the cut. It generally requires one wheeler to each 100 ft. of haul to keep a crew in continued operation.

Road Graders.—The road grader is the most commonly used and best-known machine used for general highway construction and needs no description. The later models have many devices for convenience in adjusting the cutting blade for various kinds of work, and most of them can be steered by the operator so that they are not entirely dependent upon the accuracy with which the tractor hauling them is steered. It should be noted that these machines move earth by sliding it along the surface of the road, and it is, therefore, better adapted for light or medium work than for construction requiring large amounts of material to be moved.

Elevating Graders.—The elevating grader is so arranged that a plow loosens the soil and deposits it upon a moving apron which in turn deposits it in a wagon or upon the road surface as desired. The elevating grader is used widely in grade reduction work for loading the dump wagons. It is also used in earth road construction for crowning up the middle part of the road and for general earth-road construction, depending upon size and kind.

Levelers.—In recent years there has been developed a new type of machine designed to perform the work of a light grader and road drag at one operation. In brief, the leveler consists of a truck to which is suspended a pair of long blades which form a V lying on the road with open end to the front. The width covered at one trip is often as much as 30 ft. and the action of the machine is to draw a little material from the sides of the road to the middle, smoothing out all depressions as it does so. The machine is well adapted for the purpose, but, up to this time, it has not been built with blades that can be adjusted to the curved cross-section usually specified for earth roads. It also has a tendency to leave a ridge of loose material in the middle of the road.

Maney Grader.—The Maney grader consists of a gear similar to a dump-wagon gear upon which is mounted a scraper very much like that used on wheelers, and having a capacity of about

1 cu. yd. It is used for the same kinds of work as the wheel scraper.

Dump Wagons.—A great many types of dump-bottom wagons are manufactured, and these are used for handling all sorts of road materials. They are very satisfactory for hauling earth on grade-reduction work if the haul exceeds about 1,000 ft., and are also used in connection with the elevating grader on earth-road construction. They may be had in capacities from 1 cu. yd. to 5 cu. yd. as desired, but the 1½- or 2-yd. sizes are best adapted for highway construction.

This type of wagon is commonly used for hauling broken stone, sand, gravel, and other similar surfacing materials.

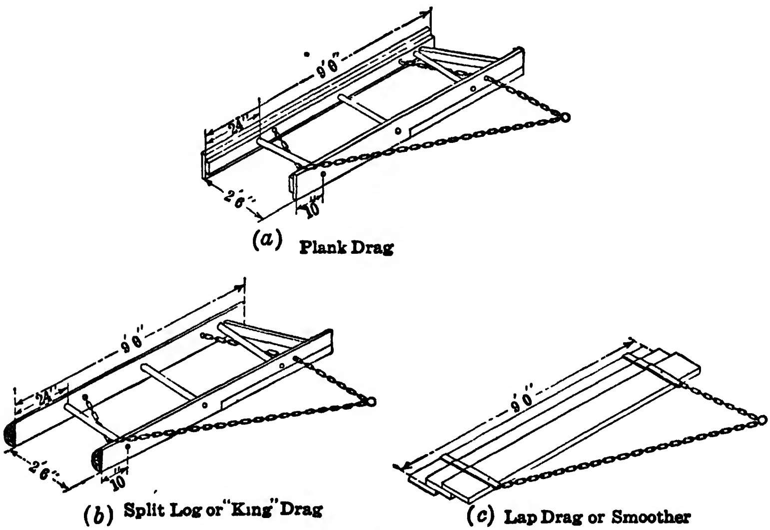


FIG. 19.—Types of road drag.

Road Drags.—The first drags used were the split-log type developed and made a factor in road maintenance by Mr. D. Ward King. This type of drag is variously constructed, but, except in details, is always much the same. It consists of the two halves of a log about 10 in. in diameter, held about 2 ft. apart by suitable cross-pieces and is provided with a chain for the hitch. The length is from 6 to 9 ft.

The plank drag is similar in form to the split-log drag except that 3 by 12-in. plank are used instead of the halves of logs. It is recommended that the front log or plank be shod with a metal

strip for at least half its length, the metal strip extending from the end of the log that is run foremost.

The lapped-plank drag consists of three or four 2-in. planks 12 in. wide nailed together with the edges overlapping. This kind of drag acts more as a smoother than as a drag, but is very satisfactory for clay soils.

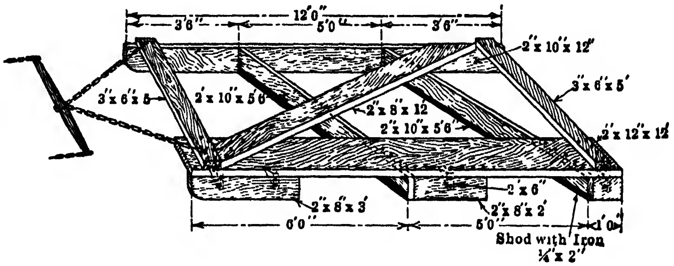


FIG. 20.—The Minnesota road planer.

Many steel drags are now offered, and they are built in the same general way as the plank drag, except that all parts are of metal. Most of them are constructed so that the blades can be tilted to any desired angle.

A new type of drag known as the Minnesota road planer has been devised by Mr. Geo. W. Cooley, State Engineer of Minnesota, which has features that give promise of great usefulness for the planer. It is shown in Fig. 20.

CHAPTER V

TESTING NON-BITUMINOUS ROAD MATERIALS

I. MATERIALS FOR MACADAM ROADS

The stone or gravel used for a macadam road is subjected to certain well-understood destructive agencies. Suitable empirical tests have been devised for determining which materials will best resist these agencies. The results of these tests are of value principally because they enable the road builder to compare materials he expects to use with materials that have proven satisfactory for similar conditions. This is, of course, the chief value of any test.

Hardness.[1]—The surface of a macadam road is subjected to the grinding action of steel tires, which tends to wear away the stone. The hardness test is designed to measure the resistance offered by a material to this action by measuring the amount that a sample will wear away under conditions that can readily be duplicated.

The machine used for the test is known as the Dorry hardness machine. It consists of a cast-iron disc about 30 in. in outside diameter and 4 in. broad which revolves in a horizontal plane. The specimen is clamped in a cast-iron clip that fits loosely in a sleeve so that the entire weight of clip and specimen serves to press the specimen against the face of the disc. The specimen is a cylinder 25 mm. in diameter, cut from the rock by means of a diamond core drill. The weight of specimen and clip at the beginning of the test is 1,250 grams. The abrasive is quartz sand between 30 and 40 mesh which is fed onto the disc from funnels placed just ahead of the specimen.

Two cylindrical test pieces are cut, dried and weighed. They are placed in the machine and the disc rotated for 1,000 revolutions, after which they are again weighed. The specimens are replaced in the machine with the other end next the disc and the grinding continued for another 1,000 revolutions. The specimens are again weighed and the average loss determined

[1] Indicates that the method has been adopted, or proposed for adoption, by the American Society for Testing Material.—Author.

for the four faces that have been abraded. The hardness is determined by the following formula, which is purely empirical:

$$\text{Hardness} = 20 - \tfrac{1}{3}W$$

where W is the average loss in grams per thousand revolutions. The Dorry test was devised years ago by the French School of Bridges and Roads, substantially in the form in which it is used today.

Toughness.[1]—The surface of a macadam is subjected to a constant pounding from horses' hoofs and from the jar of vehicles. The road stone must possess a sufficient degree of toughness to enable it to withstand the impact of traffic. To determine the degree of toughness of a rock, a sample is subjected to a series of blows from a machine similar in operation to a pile driver.

A core 25 mm. in diameter is cut from the sample to be tested and is cut to a length of 25 mm. by means of a diamond saw. The ends are carefully squared and smoothed on a grinding lap.

The Page impact machine is used for breaking the cores. This machine has a base weighing about 50 kg. upon which the core is held by suitable clips. A plunger of 1 kg. weight is placed on top of the specimen, the end of the plunger being spherical and hard-tempered. A hammer weighing 2 kg. falls on the upper end of the plunger, delivering a sharp blow to the core through the medium of the plunger. For the first blow the hammer falls from a height of 1 cm. and for each succeeding blow the height is increased 1 cm. The number of blows required to fracture the core is taken as a measure of the toughness.

Cementing Value.—The dust from most rocks will cement together when wet. This cementing action is as definite as that of Portland cement, but the resulting bond is not nearly as strong. Macadam roads are bonded by utilizing the cementing action of the stone dust, but if the larger stones are to be reasonably well cemented together the dust must possess fairly good cementing properties.

In order to measure the cementing value of a rock, briquettes are made from the dust and broken under standard conditions.

Five hundred grams of the stone to be tested are broken to pass a ½-in. screen and placed in a ball mill along with 90 c.c. of water. Two iron balls each weighing 20 lb. are used for the grinding. The grinding is continued for 2½ hr. with the mill

[1] See footnote, page 63.

running at the rate of 2,000 revolutions per hour. This is sufficient time to grind the stone and water into a stiff paste.

The paste is moulded into briquettes 25 mm. in diameter and 25 mm. long by means of a hydraulic press that subjects the briquettes to a pressure of 132 kg. per square centimeter, which pressure is maintained for only an instant.

The briquettes are dried in air for 20 hr. and then for 4 hr. in an oven which is maintained at a temperature of 200°F. The briquettes are cooled in a desiccator for about 20 min. and then broken.

The machine for breaking the briquettes consists of an anvil upon which the specimen is placed, a plunger resting upon the specimen and a hammer weighing 1 kg. which is arranged so as to fall 1 cm. at each blow. Attached to the plunger is a light steel lever at the end of which is a brass marker that can be adjusted so as to come into contact with a sheet of silicated paper. The recoil of the plunger due to the resilience of the briquette causes the marker to make a short vertical line on the paper up until the point of failure of the specimen. The silicated paper is wound on a drum that is turned slightly after each blow. The number of blows up to the time when the specimen loses its resilience is a measure of the cementing value. The average number of blows for five briquettes is the cementing value of the sample.

Abrasion.[1]—It is evident that the grinding of steel tires and the pounding of hoofs and of wheels are inseparable and a test devised by the French School of Bridges and Roads is designed to show the degree to which a rock will resist combined impact and abrasion. The Deval abrasion machine is used for this test, and consists of one or more units. Each unit consists of a cast-iron cylinder, 20 cm. inside diameter and 34 cm. deep inside. The cylinders are mounted at an angle of 30° with the axis of revolution. As the cylinder revolves the charge of stone inside is thrown from one end of the cylinder to the other, the pieces rubbing together and being pounded against the sides and ends of the cylinder and thus being subjected to both impact and abrasion.

The charge consists of pieces of rock broken to as nearly uniform size as possible and the test sample should be as nearly 50 pieces as possible. The charge must weigh within 10 grams of

[1] See footnote, page 63.

5 kg. The sample is washed and dried and then weighed and placed in one of the cylinders of the Deval machine. The machine is then run for 10,000 revolutions at a rate of between 30 and 33 revolutions per minute. The charge is then removed and all pieces that are retained on a 16-mesh screen are saved. These are washed carefully, dried and weighed. The results may be expressed in terms of per cent. of wear which is determined as follows:

$$\text{Per cent. of wear} = \frac{\text{grams lost during test}}{\text{grams weight of original sample}}$$

The results may also be expressed in terms of the French coefficient of wear as follows:

$$\text{French coefficient of wear} = 20 \times \frac{20}{W} = \frac{400}{W}$$

where W = grams lost per kilogram of original sample.

II. MATERIALS FOR SHEET AND BLOCK PAVEMENTS

Apparent Specific Gravity of Homogeneous Coarse Aggregates.[1–2]—The apparent specific gravity shall be determined in the following manner:

A properly selected sample which will pass a 2.54-cm. (1-in.) circular opening and which will not pass a 1.27-cm. (½-in.) circular opening, and approximately cubical or spherical in shape, shall be dried to constant weight at a temperature between 100° and 111°C. (212° and 230°F.).

The dried sample shall be suspended in air by a fine wire or thread from a scale or balance and weighed in air to 0.01 gram, which weight shall be recorded as weight (*a*).

It shall then be immersed, for not less than 10 min., in clear water having a temperature between 15° and 25°C. (60° and 77°F.) until no air bubbles appear on the surface of the sample.

After all air bubbles shall have been removed from the surface and after the scales have been balanced, the sample shall be allowed to remain immersed for 1 min. and, if any change in weight takes place, the sample shall remain in water until the balance remains constant within 0.01 gram for 1 min. This weight shall be recorded as weight (*b*).

After weight (*b*) has been obtained, the sample shall be re-

[1] See footnote, page 63.

[2] Attention is called to the distinction between apparent specific gravity and actual specific gravity. Apparent specific gravity includes the voids in the specimen and is therefore always less than, or equal to, never greater than, the actual specific gravity of a material.

moved immediately from the water, the surface water shall be wiped off with a towel or filter paper, and the wet sample shall be promptly weighed in air. This shall be recorded as weight (*c*).

The apparent specific gravity of the sample shall be calculated by dividing the weight of the dry specimen (wt. *a*) by the difference between the weights of the saturated specimen in air (wt. *c*) and in water (wt. *b*) as follows:

$$\text{Apparent specific gravity} = \frac{Wt.\ (a)}{Wt.\ (c) - Wt.\ (b).}$$

For sand or for aggregates consisting of sand and cement or rock dust the Jackson method of determining specific gravity is used. It is as follows:

Weigh out accurately to the tenths' place of decimals 50 grams of the dry sample of the material. Then fill the bulb and burette of the Jackson apparatus with kerosene, leaving just space enough to take the temperature by introducing a thermometer through the neck. Remove the thermometer and add sufficient kerosene to fill exactly to the mark on the neck, drawing off any excess by means of the burette. Run into the unstoppered Erlenmeyer flask of the apparatus about one-half of the kerosene in the bulb. Then pour in slowly the 50 grams of material and revolve to remove air bubbles. Run in more kerosene until any adhering dust is carefully washed from the neck of the flask, and the kerosene is just below the ground glass. Place the hollow ground-glass stopper in position, and turn it to fit tightly. Run in kerosene exactly to the 200-c.c. graduation on the neck, making sure that no air bubbles remain in the flask. Read the specific gravity from the graduation on the burette and then the temperature of the oil in the flask, noting the difference between the temperature of the oil in the bulb before the determination and the temperature of the oil in the flask after the determination.

Corrections for temperature changes during the determination are made in accordance with Tables 3 and 4 which have been compiled for general application. For exact determinations a table should be worked out experimentally for the apparatus used.

Absorption.[1]—If a rock absorbs an appreciable percentage of water, it will slowly disintegrate if subjected to freezing. In order to determine the suitability of a rock where this condition

[3] See footnote, page 63.

is encountered the amount of water it will absorb per cubic foot is determined by the following method. Two pieces are used to facilitate rapid weighing in the final test.

TABLE 3.—CORRECTION IN SPECIFIC GRAVITY IN VARIOUS PORTIONS OF THE GRADUATED SCALE DUE TO CHANGE IN TEMPERATURE, CENTIGRADE, DURING THE DETERMINATION

Read the temperature in the bulb before the determination and of the oil in the flask after the determination. Add the correction if the temperature of the oil increases, and subtract it if it decreases.

Change in temperature Centigrade	2 50 to 2 60	2 60 to 2 70	2 70 to 2 80	2 80 to 2.90	2 90 to 3.00	3 00 to 3 10	3 10 to 3.20	3 20 to 3.30	3 30 to 3.40	3 40 to 3 50
0 2°	0 00	0.01	0 01	0 01	0.01	0.01	0.01	0.01	0.01	0 01
0 4°	0 01	0.01	0.01	0.01	0 01	0 01	0.01	0.01	0 02	0 02
0 6°	0.01	0 02	0.02	0.02	0.02	0 02	0 02	0.02	0 02	0 02
0 8°	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0 03
1.0°	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0 04
1.2°	0 03	0 03	0.03	0.03	0 04	0.04	0.04	0.04	0.05	0 05
1.4°	0.03	0.04	0.04	0.04	0 04	0.05	0.05	0 05	0.06	0 06
1.6°	0.04	0.04	0 04	0 05	0.05	0 05	0 05	0.06	0.06	0 07
1.8°	0.04	0.05	0 05	0.05	0 06	0.06	0.06	0.06	0.07	0 07
2.0°	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.08	0.08
2 2°	0.05	0.06	0.06	0.06	0.07	0.07	0.08	0.08	0.09	0 09
2 4°	0.06	0.06	0.06	0.07	0.07	0 08	0.08	0.09	0.10	0 10
2 6°	0.06	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0 11
2 8°	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.12
3 0°	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.12	0.12
3 2°	0.07	0.08	0.09	0.09	0.10	0.10	0.11	0.12	0.13	0.13
3 4°	0 08	0.09	0.09	0.10	0 10	0.11	0.12	0.12	0.13	0 14
3 6°	0.08	0.09	0.10	0 10	0.11	0 12	0.12	0.13	0.14	0 15
3 8°	0.09	0.10	0.10	0.11	0.12	0 12	0.13	0.14	0.15	0 16
4.0°	0.09	0.10	0.11	0.12	0.12	0.13	0.14	0.14	0.16	0.17
4.2°	0.10	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.17	0 17
4.4°	0.10	0.11	0.12	0.13	0.13	0.14	0.15	0.16	0.17	0.18
4.6°	0.11	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19
4.8°	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.17	0.19	0.20
5.0°	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.18	0.20	0.21

First, a sample weighing between 29 and 31 grams and approximately cubical in shape shall be dried in a closed oven for

1 hr. at a temperature of 110°C. (230°F.) and then cooled in a desiccator for 1 hr. Second, the sample shall be rapidly weighed in air. Third, trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion. Fourth, after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as possible in distilled water having a temperature of 25°C. (77°F.). Fifth, allow the sample to remain 48 hr. in distilled water maintained as nearly as practicable at 25°C. (77°F.) at the termination of which time bring the water to exactly this temperature and weigh

Table 4.—Correction in Specific Gravity in Various Portions of the Grauated Scale Due to Change in Temperature, Fahrenheit, During the Determination

Read the temperature of the oil in the bulb before the determination and of the oil in the flask after the determination. Add the correction if the temperature of the oil increases, and subtract if it decreases.

Change in temperature Fahrenheit	2 50 to 2.60	2 60 to 2 70	2 70 to 2.80	2 80 to 2 90	2 90 to 3 00	3 00 to 3 10	3 10 to 3.20	3 20 to 3.30	3.30 to 3 40	3.40 to 3.50
0.5°	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1.0°	0 01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1.5°	0.02	0.02	0.02	0 02	0 03	0.03	0 03	0.03	0.03	0 03
2.0°	0.03	0.03	0.03	0 03	0 03	0.04	0.04	0.04	0.04	0 05
2.5°	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.06	0.06
3.0°	0.04	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0 07	0 07
3.5°	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.08	0 08
4.0°	0.05	0 06	0.06	0.06	0.07	0 07	0 08	0.08	0.09	0 09
4.5°	0.06	0.06	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0 10
5 0°	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.12
5.5°	0 07	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.12	0.13
6.0°	0.08	0.08	0.09	0.10	0.10	0.11	0.11	0.12	0.13	0.14
6.5°	0.08	0.09	0.10	0.10	0.11	0.12	0.12	0.13	0.14	0 15
7.0°	0.09	0.10	0.11	0.11	0.12	0.13	0.13	0.14	0.15	0.16
7.5°	0.10	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.17	0.17
8.0°	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.18	0.18
8.5°	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.19	0.20
9.0°	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.18	0.20	0.21
9.5°	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.21	0.22
10.0°	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.22	0.23

the sample while immersed in it. Sixth, the number of pounds of water absorbed per cubic foot of the sample shall be calculated by the following formula.

$$\text{Pounds of water absorbed per cubic foot} = \frac{W_2 - W_1}{W - W_1} \times 62.24$$

where W = weight in grams of sample in air,
W_1 = weight in grams of sample in water just after immersion,
W_2 = weight in grams of sample in water after 48 hr. immersion,
62.24 = weight in pounds of a cubic foot of distilled water having a temperature of 25°C. (77°F.).

Voids.—In proportioning aggregates for concrete road surfaces, and in proportioning the mineral aggregate for various types of bituminous surfaces, it is desirable to know the percentages of voids in the aggregate. For coarse aggregates or those containing stones above ½ in. in size, the Schuette cone method is employed. To use this method the specific gravity must be determined by one of the methods already described. The Schuette cone method of determining voids is as follows:[1]

The Schuette cone is a truncated cone made of No. 18 B. & S. gage galvanized steel with calked seams and having the following dimensions: Overall diameter of bottom, 25.4 cm. (10 in.); overall height 25.4 cm. (10 in.); inside diameter of opening, 7.6 cm. (3 in.).

The aggregate is thoroughly mixed by rolling on paper and placed in the cone, segregation being avoided. The aggregate is then compacted in the cone by oscillation on the edge of the cone while it is resting on a wooden floor, wooden box or block of wood. Cotton waste is pressed against the surface of the aggregate to prevent segregation during oscillation. As the material settles in the cone, aggregate is added until the cone is full of thoroughly compacted aggregate, which process will require from 300 to 500 oscillations. Then weigh the cone filled with aggregate; weigh the cone empty; weigh the cone full of clean water. The percentage of voids in the aggregate is calculated by the following formula:

$$\text{Percentage of voids} = \left\{1 - \frac{C - A}{(B - A)\,D}\right\}100$$

in which A = the weight of the cone in grams; B = the weight in grams of the cone filled with water; C = the weight in grams

[1] See footnote page 63.

of the cone filled with compacted aggregate; D = the specific gravity of the aggregate.

For determining the voids in sand or other fine mineral aggregate the following method is satisfactory.

First determine the specific gravity of the aggregate by means of the Jackson apparatus. Weigh not less than 250 grams of the mixture and then compact in a glass graduate by gently tapping the graduate on a table top until the volume of the mixture cannot be decreased. Read the volume in c.c.

$$\text{Percentage of voids} = \left\{1 - \frac{\text{weight of sample}}{\text{volume of sample} \times \text{sp. gr. of sample}}\right\}100$$

If the voids are to be determined in material ½ in. in size and larger, the pouring method can be used for approximate determinations which are accurate enough for many purposes. A measured quantity of the aggegate is packed in a vessel and water is added until the voids are filled. The quantity of water necessary is the measure of the volume of voids.

Sieve Analysis.—The sieve analysis is used as a means of determining the grading of mixtures of mineral aggregates used in paving construction. For ordinary analysis of concrete materials the familiar methods employed for sand analysis are commonly used. It is convenient to select a set of screens of such sizes that the area of the opening per mesh doubles for each successive sieve. A set having the following sizes of openings is made by the W. S. Tyler Co., Cleveland, Ohio, and is very satisfactory for this purpose:

TABLE 5.—SHOWING SIZE OF OPENINGS IN SIEVES OF LOGARITHMIC SCREEN SCALE

Meshes per inch	Size of openings in inches
200	0.0029
150	0.0041
100	0.0058
65	0.0082
48	0.0116
35	0.0164
28	0.0232
20	0.0328
14	0.0460
10	0.0650
8	0.0930
6	0.1310
4	0.1850
3	0.2630

The result of the screen analysis may be used in tabular form, but it is more often platted as the sieve-analysis curve.

The grading of the mineral aggregates for sheet asphalt and asphaltic concrete pavements is examined by means of the sieve analysis. For this purpose the following sieves have been adopted as standard by the American Society for Testing Materials:

TABLE 6.—SHOWING STANDARD SIZES OF SIEVES FOR ROAD MATERIALS TESTING

Meshes per linear inch	Diameter of wire, inches
200	0.00235
100	0.00450
80	0.00575
50	0 00900
40	0.01025
30	0 01375
20	0 01650
10	0 02700

The results of the sieve analysis on paving mixtures are usually recorded in tabular form, but it is often convenient to use

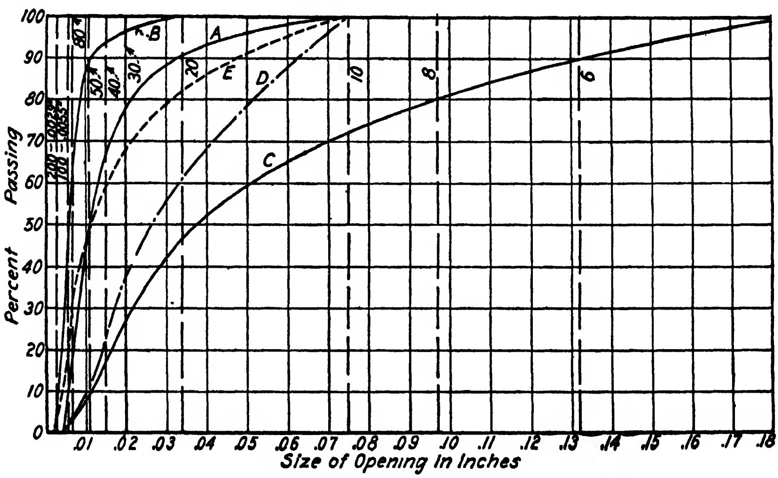


FIG. 21.

the sieve-analysis curve, especially when combining two or more sands to secure a desired mixture. To illustrate this method, let Fig. 21 represent the sieve-analysis curves for two sands *B* and *C*, and let *A* represent the sieve-analysis curve for the desired mixture. The problem is to determine what mixtures of sands *B* and *C* will come most nearly to the grading of curve *A*.

It is seen that sand *C* includes 28 per cent. of material larger than 10-mesh. This would be screened out at the paving plant and rejected. The first step is to determine the grading of sand *C* after the oversize has been rejected. Since 72 per cent. of the sand passes the 10-mesh sieve, it is only necessary to determine the percentages of the various sizes passing when 72 per cent. becomes 100 per cent., which is done by dividing the per cent. passing each sieve by 0.72. The result is shown by curve *D*. The next step is best illustrated by the following table of computations showing the amount of each size of sand necessary to produce the mixture desired:

Size of sieve	Per cent of sand *B* to use	Per cent of sand *C* to use
20	75	25
30	68	32
40	63	37
50	50	50
80	32	68
100	20	80
	6)308	6)292
	51⅓	48⅔

The combination of sands *B* and *C* that will produce a sand most nearly like *A* that can be made with them is, therefore, the one in which 52 per cent. sand *B* and 48 per cent. sand *C* is mixed. Assume that it is desired to produce 1,000 grams of sand *A* to check the mixture and the quantity of each size that will be obtained is shown in the following table:

Size of sieve	Sand *B* grams	Sand *C* grams	Resulting total grams	Mixture, per cent. pass
10 to 20	0 0	182 0	182	81 8
20 to 30	21.0	125 0	146	67 2
30 to 40	21 0	63 0	84	58 8
40 to 50	21.0	57.0	78	51 0
50 to 80	161.0	34 0	195	31 5
80 to 100	62.5	9.5	72	24 3
Below 100	234.0	9 5	243	
			1006	

From the last column the curve for the sand produced by the mixing can be platted and it is shown as curve *E*. The sand produced contains too much fine material (80- and 100-mesh)

except for the heaviest traffic, but it is the most nearly like the ideal that could be produced by mixing the two sands shown. In practice a third would be added to decrease the percentage of fine sand or part of the fine sand would be removed by washing or otherwise. This, however, illustrates the method of utilizing the sieve-analysis curves.

Mechanical Analysis of Sand or Other Fine Highway Material, Except for Fine Aggregate Used in Cement Concrete.[1]—The method shall consist of, first, drying at not over 110°C. (230°F.) to a constant weight a sample weighing 50 grams; second, passing the sample through each of the American Society for Testing Materials standard sieves; third, determining the percentage by weight retained on each sieve, the sifting being continued on each sieve until less than 1 per cent. of the weight retained on each sieve shall pass through the sieve during the last minute of sifting; fourth, recording the mechanical analysis in the following manner:[2]

Passing 200-mesh sieve.	=	.	Per cent.
Passing 100-mesh sieve and retained on a 200-mesh sieve.	=	.	Per cent.
Passing 80-mesh sieve and retained on a 100-mesh sieve.	=	.	Per cent.
Passing 50-mesh sieve and retained on a 80-mesh sieve.	=	.	Per cent.
Passing .	=		Per cent.
		100 00	Per cent.

Mechanical Analysis of Broken Stone or Broken Slag, Except for Aggregate Used in Cement Concrete.[1]—The method shall consist in, first, drying at not over 110°C. (230°F.) to a constant weight a sample weighing in pounds six times the diameter in inches of the largest holes required; second, passing the sample through such of the following sized screens having circular openings as are required or called for by the specification, screens to be used in the order named: 8.89 cm. (3½ in.), 7.62 cm. (3 in.), 6.35 cm. (2½ in.), 5.08 cm. (2 in.), 3.81 cm. (1½ in.), 3.18 cm. (1¼ in.), 2.54 cm. (1 in.), 1.90 cm. (¾ in.), 1.27 cm. (½ in.) and 0.64 cm. (¼ in.); third, determining the percent-

[1] See footnote, page 63.

[2] The order in which the sieves are to be used in the process of sifting is immaterial and shall be left optional; but in reporting results the order in which the sieves have been used shall be stated.

age by weight retained on each screen; fourth, recording the mechanical analysis in the following manner:

Passing 0 64-cm. (1/4-in.) screen .	=	Per cent.
Passing 1 27-cm. (1/2-in.) screen and retained on a 0 64-cm. (1/4-in.) screen.	= .	Per cent.
Passing 1 90-cm. (3/4-in.) screen and retained on a 1 27-cm. (1/2-in.) screen. ..	=	Per cent.
Passing 2 54-cm. (1-in.) screen and retained on a 1 90-cm. (3/4-in.) screen.	=	Per cent.
		100 00 Per cent.

Mechanical Analysis of Mixtures of Sand or Other Fine Material With Broken Stone or Broken Slag, Except for Aggregates Used in Cement Concrete.[1]—The method shall consist in, first drying at not over 110°C. (230°F.) to a constant weight a sample weighing in pounds six times the diameter in inches of the largest holes required; second, separating the sample by the use of a screen having circular openings, 0.64 cm. (1/4 in.) in diameter; third, examining the portion retained on the screen in accordance with the Method for Making a Mechanical Analysis of Broken Stone or Broken Slag; fourth, examining the portion passing this screen in accordance with the Method for Making a Mechanical Analysis of Sand or Other Fine Highway Material; fifth, recording the mechanical analysis in the following manner:

Passing 200-mesh sieve . .	=	Per cent.
Passing 100-mesh sieve and retained on a 200-mesh sieve	=	Per cent.
Passing 80-mesh sieve and retained on a 100-mesh sieve.	=	Per cent.
Passing 10-mesh sieve and retained on a 20-mesh sieve	. =	Per cent.
Passing 0 64-cm. (1/4-in.) screen and retained on a 10-mesh sieve.	. =	. Per cent.
Passing 1 27-cm. (1/2-in.) screen and retained on a 0 64-cm. (1/4-in.) screen.........	. =	. . Per cent.
Passing 1 90-cm. (3/4-in.) screen and retained on a 1.27-cm. (1/2-in.) screen	=	.. ... Per cent.
Passing	=	.. . Per cent.
		100.00 Per cent.

[1] See footnote, page 63.

Tests of Paving Brick.[1]—The quality and acceptability of paving brick, in the absence of other special tests mutually agreed upon in advance by the seller on the one side and the buyer on the other side, shall be determined by the following procedure:

I. The rattler test, for the purpose of determining whether the material as a whole possesses to a sufficient degree strength, toughness and hardness.

II. Visual inspection, for the purpose of determining whether the physical properties of the material as to dimensions, accuracy and uniformity of shape and color, are in general satisfactory, and for the purpose of culling out from the shipment individually imperfect or unsatisfactory brick.

The acceptance of paving brick as satisfactorily meeting one of these tests shall not be construed as in any way waiving the other.

I. THE RATTLER TEST

The Selection of Samples for Testing

1. Place of Sampling.—In general, where a shipment of bricks involving a quantity of less than 100,000 is under consideration, the sampling may be done either at the brick factory prior to shipment, or on cars at their destination or on the street when delivered ready for use. When the quantity under consideration exceeds 100,000 the sampling shall be done at the factory prior to shipment. Bricks accepted as the result of test prior to shipment shall not be liable to subsequent rejection as a whole, but are subject to such culling as is provided for under Part II, visual inspection.

2. Method of Selecting Samples.—In general, the buyer shall select his own samples from the material which the seller proposes to furnish. The seller shall have the right to be present during the selection of a sample. The sampler shall endeavor, to the best of his judgment, to select brick representing the average of the lot. No samples shall include bricks which would be rejected by visual inspection as provided in Part II except that where controversy arises, whole tests may be selected to determine the admissibility of certain types or portions of the lot having a characteristic appearance in common. In cases where prolonged controversy occurs between buyer and seller and samples

[1] Standard specification adopted by the American Society for Testing Materials, 1915.

selected by each party fail to show reasonable concurrence, then both parties shall unite in the selection of a disinterested person to select the samples, and both parties shall be bound by the results of samples thus selected.

3. Number of Samples per Lot.—In general, one sample of ten bricks shall be tested for every 10,000 bricks contained in the lot under consideration; but where the total quantity exceeds 100,000 the number of samples tested may be fewer than one per 10,000 provided that they shall be distributed as uniformly as practicable over the entire lot.

4. Shipment of Samples.—Samples which must be transported long distances by freight or express shall be carefully put up in packages holding not more than twelve bricks each. When more than six bricks are shipped in one package, it shall be so arranged as to carry two parallel rows of bricks side by side, and these rows shall be separated by a partition. In event of some of the bricks being cracked or broken in transit, the sample shall be disqualified if there are not remaining ten sound undamaged bricks.

5. Storage and Care of Samples.—Samples shall be carefully handled to avoid breakage or injury. They shall be kept in the dry so far as practicable. If wet when received or known to have been immersed or subjected to recent prolonged wetting, they shall be dried for at least 6 hr. in a temperature of 100°F. before testing.

The Construction of the Rattler

6. General Design.—The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described.

7. The Barrel.—The barrel of the machine shall be made up of the heads, headliners, staves and stave-liners.

The heads may be cast in one piece with the trunnions, which shall be $2\frac{1}{2}$ in. in diameter, and shall have a bearing 6 in. in length, or they may be cast with heavy hubs, which shall be bored out for $2\frac{7}{16}$-in. shafts, and shall be keyseated for two keys, each $\frac{1}{2}$ by $\frac{3}{8}$ in. and spaced 90° apart. The shaft shall be a snug fit and when keyed shall be entirely free from lost motion. The distance from the end of the shaft or trunnion to the inside

face of the head shall be 15⅜ in. in the head for the driving end of the rattler, and 11⅜ in. for the other head, and the distance from the face of the hubs to the inside face of the heads shall be 5⅛ in.

The heads shall be not less than ¾ in. thick, nor more than ⅞ in. thick. In outline, each head shall be a regular 14-sided polygon inscribed in a circle 28⅜ in. in diameter. Each head shall be provided with flanges not less than ¾ in. thick and extending outward 2½ in. from the inside face of the head to afford a means of fastening the staves. The surface of the flanges of the head shall be smooth and give a true and uniform bearing for the staves. To secure the desired true and uniform bearing the surfaces of the flanges of the head shall be either ground or machined. The flanges shall be slotted on the outer edge, so as to provide for two ¾-in. bolts at each end of each stave, said slots to be 13/16 in. wide and 2¾ in. center to center. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. Between each two slots there shall be a brace ⅜ in. thick, extending down the outward side of the head not less than 2 in.

There shall be for each head a cast-iron headliner 1 in. thick and conforming to the outline of the head, but inscribed in a circle 28⅛ in. in diameter. This headliner shall be fastened to the head by seven ⅝-in. cap-screws, through the head from the outside. Whenever these headliners become worn down ½ in. below their initial surface level at any point of their surface, they shall be replaced by new liners; they shall be hard machinery iron and should contain not less than 1 per cent. of combined carbon.

The staves shall be made of 6-in. medium-steel structural channels, 27¼ in. long and weighing 15.5 lb. per lineal foot. The staves shall have two holes 13/16 in. in diameter, drilled in each end, the center line of the holes being 1 in. from the end and 1⅜ in. either way from the longitudinal center line. The spaces between the staves shall be as uniform as practicable, but shall not exceed 5/16 in.

The interior or flat side of each stave shall be protected by a liner ⅜ in. thick by 5½ in. wide by 19¾ in. long. The liner shall consist of medium-steel plate, and shall be riveted to the channel by three ½-in. rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line

and spaced 7 in. from the center each way. The rivet holes shall be countersunk on the face of the liner and the rivets shall be driven hot and chipped off flush with the surface of the liners. These liners shall be inspected from time to time, and if found loose shall be at once re-riveted.

Any test at the expiration of which a stave-liner is found detached from the stave or seriously out of position shall be rejected. When a new rattler, in which a complete set of new staves is furnished, is first put into operation, it shall be charged with 400 lb. of shot of the same sizes, and in the same proportions as provided in Section 9, and shall then be run for 18,000 revolutions at the usual prescribed rate of speed. The shot shall then be removed and a standard shot charge inserted; after which the rattler may be charged with brick for a test.

No stave shall be used for more than 70 consecutive tests without renewing its lining. Two of the 14 staves shall be removed and relined at a time in such a way that of each pair one falls upon one side of the barrel and the other upon the opposite side, and also so that the staves changed shall be consecutive but not contiguous; for example, 1 and 8, 3 and 10, 5 and 12, 7 and 14, 2 and 9, 4 and 11, 6 and 13, etc., to the end that the interior of the barrel at all times shall present the same relative condition of repair. The changes in the staves should be made at the time when the shot charges are being corrected, and the record must show the number of charges run since the last pair of new-lined staves was placed in position.

The staves when bolted to the heads shall form a barrel 20 in. long inside measurement, between headliners. The liners of the staves shall be so placed as to drop between the headliners. The staves shall be bolted tightly to the heads by four ¾-in. bolts, and each bolt shall be provided with a lock nut, and shall be inspected at not less frequent intervals than every fifth test and all nuts kept tight. A record shall be made after each inspection showing in what condition the bolts were found.

8. The Frame and Driving Mechanism.—The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidty to support it without undue vibration. It shall rest on a rigid foundation with or without the interposition of wooden plates, and shall be fastened thereto by bolts at not less than four points.

It shall be driven by gearing whose ratio of driver to driven is not less than one to four. The countershaft upon which the

driving pinion is mounted shall be not less than $1^{15}/_{16}$ in. in diameter, with bearing not less than 6 in. in length. If a belt drive is used, the pulley shall be not less than 18 in. in diameter and $6\frac{1}{2}$ in. in face. A belt at least 6 in. in width properly adjusted, to avoid unnecessary slipping, should be used.

9. The Abrasive Charge.—The abrasive charge shall consist of cast-iron spheres of two sizes. When new the larger spheres shall be 3.75 in. in diameter and shall weigh approximately 7.5 lb. (3.40 kg.) each. Ten spheres of this size shall be used.

These shall be weighed separately after each ten tests, and if the weight of any large sphere falls to 7 lb. (3.175 kg.) it shall be discarded and a new one substituted; provided, however, that all of the large spheres shall not be discarded and substituted by new ones at any single time, and that so far as possible the large spheres shall compose a graduated series in various stages of wear.

When new, the smaller spheres shall be 1.875 in. in diameter and shall weigh approximately 0.95 lb. (0.43 kg.) each. In general the number of small spheres in a charge shall not fall below 245 nor exceed 260. The collective weight of the large and small spheres shall be as nearly 300 lb. as possible. No small sphere shall be retained in use after it has been worn down so that it will pass a circular hole 1.75 in. in diameter, drilled in an iron plate $\frac{1}{4}$ in. in thickness, or weigh less than 0.75 lb. (0.34 kg.). Further, the small spheres shall be tested by passing them over the above plate or by weighing after every ten tests, and any which pass through or fall below the specified weight shall be replaced by new spheres; provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that, so far as possible, the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall be at once replaced.

The iron composing these spheres shall have a chemical composition within the following limits:

TABLE 7.—SHOWING COMPOSITION OF STANDARD BRICK RATTLER SHOT

Combined carbon	Not under 2.50 per cent.
Graphitic carbon	Not over 0 25 per cent.
Silicon.	Not over 1.00 per cent.
Manganese..	Not over 0.50 per cent.
Phosphorus	Not over 0.25 per cent.
Sulfur	Not over 0.08 per cent.

For each new batch of spheres used, the chemical analysis shall be furnished by the maker or be obtained by the user, before introducing into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

The Operation of the Test

10. The Brick Charge.—The number of bricks per test shall be ten for all bricks of so-called "block-size," whose dimensions fall between 8 and 9 in. in length, 3 and $3\frac{3}{4}$ in. in width, and $3\frac{3}{4}$ and $4\frac{1}{4}$ in. in thickness. No brick should be selected as part of a regular test that would be rejected by any other requirements of the specifications under which the purchase is made.

11. Speed and Duration of Revolution.—The rattler shall be rotated at a uniform rate of not less than 29.5 nor more than 30.5 revolutions per minute, and 1,800 revolutions shall constitute the test. A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed 10 revolutions will be allowed for stopping. Only one start and stop per test is generally acceptable. If, from accidental causes, the rattler is stopped and started more than once during a test, and the loss exceeds the maximum permissible under the specifications, the test shall be disqualified and another made.

12. The Scales.—The scales must have a capacity of not less than 300 lb., and must be sensitive to 0.5 oz., and must be tested by a standard test weight at intervals of not less than every ten tests.

13. The Results.—The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick, any piece weighing less than 1 lb. shall be rejected.

14. The Records.—A complete and continuous record shall be kept of the operation of all rattlers working under these specifications. This record shall contain the following data concerning each test made:

1. The name of the person, firm or corporation furnishing each sample tested.

2. The name of the maker of the brick represented in each sample tested.

3. The name of the street or contract which the sample represented.

4. The brands or marks upon the bricks by which they were identified.

5. The number of bricks furnished.

6. The date on which they were received for test.

7. The date on which they were tested.

8. The drying treatment given before testing, if any.

9. The length, breadth and thickness of the bricks.

10. The collective weight of the ten large spherical shot used in making the test at the time of their last standardization.

11. The number and collective weight of the small spherical shot used in making the test, at the time of their last standardization.

12. The total weight of the shot charge, after its last standardization.

13. Certificate of the operator that he examined the condition of the machine as to staves, liners, and any other parts affecting the barrel, and found them right at the beginning of the test.

14. Certificate of the operator of the number of charges tested since the last standardization of shot charge and last renewals of stave-liners.

15. The time of the beginning and ending of each test, and the number of revolutions made by the barrel during the test, as shown by the indicator.

16. Certificate of the operator as to number of stops and starts made in each test.

17. The initial collective weight of the ten bricks composing the charge and their collective weight after rattling.

18. The loss calculated in percentage of the initial weight; and the calculation itself.

19. The number of broken bricks and remarks upon the portions which were included in the final weighing.

20. General remarks upon the test and any irregularities occurring in its execution.

21. The location of the rattler and name of the owner, upon which the test was made.

22. The certificate of the operator that the test was made under the specifications of the American Society for Testing Materials and that the record is a true record.

23. The signature of the operator or person responsible for the test.

24. The serial number of the test.

In the event of more than one copy of the record of any test being required, they may be furnished on separate sheets, and marked duplicates, but the original record shall always be preserved intact and complete.

For the convenience of the public, the accompanying blank form which provides space for the necessary data, is furnished and its use recommended.

Acceptance and Rejection of Material

15. Basis of Acceptance or Rejection.—Paving bricks shall not be judged for acceptance or rejection by the results of individual tests; but by the average of no less than five tests. Where a lot of bricks fail to meet the required average, it shall be optional with the buyer whether the bricks shall be definitely rejected or whether they may be regraded and a portion selected for further test as provided in Section 16.

16. Range of Fluctuation.—Some fluctuation in the results of the rattler test, both on account of variations in the bricks and in the machine used in testing, are unavoidable, and a reasonable allowance for such fluctuations should be made wherever the standard may be fixed.

In any lot of paving brick, if the loss on a test computed upon its initial weight exceeds the standard loss by more than 2 per cent., then the portion of the lot represented by that test shall at once be resampled and three more tests executed upon it, and if any of these three tests shall again exceed by more than 2 per cent. the required standard, then that portion of the lot shall be rejected.

If in any lot of brick two or more tests exceed the permissible maximum, then the buyer may at his option reject the entire lot, even though the average of all the tests executed may be within the required limits.

17. Fixing of Standards.—The percentage of loss which may be taken as the standard will not be fixed in these specifications, and shall remain within the province of the contracting parties. For the information of the public, the following scale of average losses is given, representing what may be expected of tests executed under the foregoing specifications:

TABLE 8.—RECOMMENDED RATTLER LOSS SPECIFICATIONS

	General average loss, per cent.	Maximum permissible loss, per cent.
For bricks suitable for heavy traffic..	22	24
For bricks suitable for medium traffic.	24	26
For bricks suitable for light traffic...	26	28

Which of these grades should be specified in any given district and for any given purpose is a matter wholly within the province of the buyer, and should be governed by the kind and amount of traffic to be carried and the quality of paving bricks available.

18. Culling and Retesting.—Where, under Sections 15 and 16 a lot or portion of a lot of bricks is rejected, either by reason of failure to show a low enough average test or because of tests above the permissible maximum, the buyer may at his option permit the seller to regrade the rejected brick, separating out that portion which he considers at fault and retaining that which he considers good. When the regrading is complete, the good portion shall be then resampled and retested, under the original conditions, and if it fails again either in average or in permissible maximum, then the buyer may definitely and finally reject the entire lot or portion under test.

19. Payment of Cost of Testing.—Unless otherwise specified, the cost of testing the material as delivered or prepared for delivery, up to the prescribed number of tests for valid acceptance or rejection of the lot, shall be paid by the buyer (see also Section 23). The cost of testing extra samples made necessary by the failure of the whole lot or any portion of it shall be paid by the seller whether the material is finally accepted or rejected.

II. VISUAL INSPECTION

It shall be the right of the buyer to inspect the bricks, subsequent to their delivery at the place of use, and prior to or during laying, to cull out and reject upon the following grounds:

20. All bricks which are broken in two or chipped in such a manner that neither wearing surface remains substantially intact, or that the lower or bearing surface is reduced in area by more than one-fifth. Where bricks are rejected upon this ground it shall be the duty of the purchaser to use them so far as practicable in obtaining the necessary half-bricks for breaking courses and making closures, instead of breaking otherwise whole and sound bricks for this purpose.

21. All bricks which are cracked in such a degree as to produce defects such as are defined in Section 20, either from shocks received in shipment and handling, or from defective conditions of manufacture, especially in drying, burning or cooling, unless such cracks are plainly superficial and not such as to perceptibly weaken the resistance of the brick to its conditions of use.

22. All bricks which are so off size, or so misshapen, bent, twisted or kiln-marked that they will not form a proper surface as defined by the paving specifications, or align with other bricks without making joints other than those permitted in the paving specifications.

23. All bricks which are obviously too soft and too poorly vitrified to endure street wear. When any disagreement arises between buyer and seller under this item, it shall be the right of the buyer to make two or more rattler tests of the brick which he wishes to exclude, as provided in Section 2, and if in either or both tests the bricks fall beyond the maximum rattler losses permitted under the specifications, then all bricks having the same objectionable appearance may be excluded and the seller shall pay for the cost of the test. But if, under such procedure, the bricks which have been tested as objectionable shall pass the rattler test, both tests falling within the permitted maximum, then the buyer cannot exclude the class of material represented by this test and he shall pay for the cost of the test.

24. All bricks which differ so markedly in color from the type or average of the shipment, as to make the resultant pavement checkered or disagreeably mottled in appearance. This section shall not be held to apply to the normal variations in color which may occur in the product of one plant among bricks which will meet the rattler test as referred to in Sections 15, 16 and 17, but shall apply only to differences of color which imply differences in the material of which the bricks are made, or extreme differences in manufacture.

OFFICIAL RECORD FORMS

Serial No..........

Report of Standard Rattler Test of Paving Brick

Identification Data

Name of the firm furnishing sample. .. ..
Name of the firm manufacturing sample . .. .
Street or job which sample represents . .. .
Brands or marks on the brick . . ..
Quantity furnished . . . . .Drying treatment. ....
Date received ... . Date tested ....
Length Breadth Thickness.. . . ..

Standardization Data

Weight of charge (after standardization)	Condition of locknuts	Condition of scales	Number and position of fresh stave-liners	Repairs (Note any repairs affecting the condition of the barrel)
10 large spheres small spheres Total .				

Number of charges tested since last inspection

Running Data

Time readings	Hours	Minutes	Seconds	Revolution counter-readings	Running notes, stops, etc
Beginning of test.					
Final reading..					

Weights an Calculations

		Percentage loss (Note—The calculation must appear)
Initial weight of ten bricks..		
Final weight of same.		
Loss of weight.. .		

Number of broken bricks and remarks on same... ...

I certify that the foregoing test was made under the specifications of the American Society for Testing Materials, and is a true record.

(Signature of tester) . .. .

Date............. . .. .

Location of laboratory..........................

CHAPTER VI

SAND-CLAY ROADS

The name sand-clay is given to a type of road surface that consists of natural or artificial mixtures of sand and clay, loam or gypsum, or of all of these materials. Such surfaces are constructed on clay, loam or gumbo soils and on deep sand. The character of the sand and of the soils encountered varies so greatly that it is impossible to lay down specific rules and proportions for the construction that will have universal application. Surprising results are often obtained with most unpromising materials and under unscientific methods of construction, yet in general the best results are obtained when a few well-established principles are observed. The methods of construction and the combinations of materials that have been most successful and the principles involved may profitably be studied.

The essential requirements for success are that the materials be reasonably suitable in character, and that they be thoroughly mixed. The aim is to secure on the surface of the road a layer or crust which is made up of sand into which has been introduced a binder of clay, loam, or gypsum and clay. The amount of this binder needed is approximately that which will fill the voids in the sand, and as a rule the more nearly that amount is used, the better the results will be. Lumps of clay or other binder are to be avoided and thorough and persistent mixing is, therefore, imperative. If natural mixtures of sand and clay are used, these will rarely be uniform, and after they are spread on the road they must be mixed to secure a homogeneous layer.

TYPES OF SOILS

Gumbo.—This soil is the familiar black or yellow waxy soil found in widely scattered localities throughout the United States. It is exceedingly fine-grained, dense, sticky and when wet rolls up on the wheels of vehicles until they become solid balls of mud. It is broadly classed as a clayey soil.

Slaking Clay.—This type of clay is found mixed with a varying percentage of sand, is somewhat coarse-grained and becomes soft

and mushy when wet. It is a yellow to reddish color and of varying degrees of stickiness. Since it is not uniformly sticky and is unstable when wet, it is not the best material to use on a deep sand soil, but where it is the only material available, it is used with more or less satisfactory results.

Semi-plastic Clay.—This material is of a gray, yellow, or reddish color, of fine texture, tough, dense, and in physical characteristics resembles gumbo. Since it is sticky and fairly stable when wet, it is a good binder for a sand road, but on account of its physical characteristics it is more difficult to handle than the slaking clay.

Sand-clay Soils.—In some localities there is found a soil which consists of a natural mixture of sand and one of the types of clay, proportioned about right for road surfacing. If deficient either in sand or clay, the mixture can be adjusted during the construction by the addition of the material that is lacking. The soil is rarely uniform in composition, and usually must be mixed on the road to secure a homogeneous surface layer.

Loam.—Loam is a brown or black, porous, coarse-grained soil containing varying percentages of sand. It is not a good material for road surfacing on account of its poor bonding properties and its lack of stability, but it is sometimes the only material available in a region of sand roads. Its use is advisable only under such conditions.

Sand.—The sand soils vary greatly in fineness and clay or loam content. When deep and free from clay or other bonding material they become loose when dry and in this condition on a highway they make a surface of very high tractive resistance. If on a low-lying road so that they are constantly water-saturated, they remain fairly stable, but in such instances are not of interest in this discussion.

Gypsum.—In a few localities, notably western Kansas, there are deposits of a mixture of gypsum and clay, together with more or less sand and gravel. The gypsum serves to augment the bonding effect of the clay, and these mixtures when incorporated with a sandy road make an excellent sand-clay, or as commonly designated, gypsum road.

SAND-CLAY CONSTRUCTION ON GUMBO, CLAY OR LOAM

When the natural soil is gumbo, clay or loam, the general method of construction is identical but varies in detail. The

object sought is to secure stability by the addition of sand or a sand-clay mixture.

I. By Addition of Natural Sand-clay Mixtures.—The road to be improved is graded so that proper side ditches are obtained. The middle portion is made about flat, as shown by Fig. 22. Upon this section the natural sand-clay mixture is spread in a layer about 10 in. thick at the middle and 6 in. at the edge, the width being from 10 to 16 ft. The sand-clay mixture is smoothed

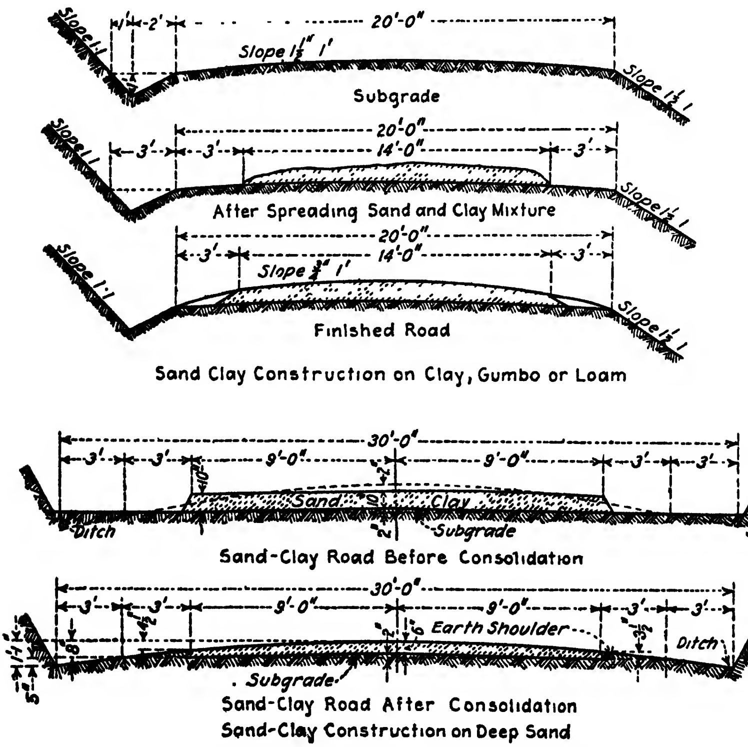


FIG. 22.—Cross-sections for sand clay roads.

with a grader and as soon as thoroughly soaked by rains is harrowed to break up the lumps and mix the materials until a layer of uniform texture is obtained. The road is then reshaped with a blade grader and is ready for traffic. If the natural sand-clay mixture is deficient either in clay or sand, the material that is lacking is added before the mixing is done.

II. By Addition of Sand.—The roadway is shaped as described before and the surface to be covered with sand is plowed to loosen

it. The sand is spread on the surface to a depth of about 6 in. While still dry the road is plowed again to mix the soil and the sand. After the plowing the mixing is completed with a disc harrow and this can best be done when the road is wet. After a thorough mixture is obtained, the surface is shaped with a grader and is compacted by traffic.

The same results are obtained by spreading the sand or fine gravel on the road in a layer 3 or 4 in. thick and allowing traffic to use it. When the road is soft after rains, the sand will be mixed with the soil and if it appears that additional sand is needed, it is added. This method is less effective than the one first described, but in time a serviceable road will result if it is given proper attention and is kept free of ruts.

SAND-CLAY CONSTRUCTION ON SAND

I. By Addition of Natural Sand-clay Mixtures.—The sandy road is shaped to a slightly crowned section with shallow ditches and with a nearly flat section in the middle portion upon which the clay mixture is to be placed. The sand-clay mixture is then spread on the sand in a layer about 10 in. thick at the middle and 6 in. thick at the edges, and when wet is thoroughly mixed with a harrow and smoothed with a grader. If the sand-clay mixture is deficient in sand, the defect is remedied by throwing on sand from the roadside. The mixing is done merely to secure uniformity of the surface and not to mix the surface material with the sand.

II. By Addition of Clay.—The amount of clay that should be added is theoretically the amount necessary to fill the voids in the sand in a layer the desired thickness. The voids can be determined by the water-displacement method which will indicate roughly the amount of clay to use. A somewhat larger proportion of clay of the slaking type is needed than of semi-plastic clay. The use of too much clay should be carefully avoided. Enough clay is spread on the surface of the sand road to fill the voids in a layer about 10 in. thick. This is then mixed with the sand by plowing and discing until a thorough mixture is obtained and the mixing must be done while the road is wet. This is the vital part of the construction and is a tedious and disagreeable job but the success of the construction depends upon the thoroughness with which it is done. The surface is then smoothed with the blade grader and is compacted by traffic.

Where no clay can be found to mix with the sand and no natural sand-clay mixtures are available, loam is used instead. The construction is carried out as just described. The results to be expected are not as good as if proper materials were available but a crust is formed that will be serviceable except in long-continued dry weather. It is apt to break through to the sand if not made of ample thickness.

Gypsum Roads.—This type is almost always constructed on sandy soils and the method of construction is the same as described for the placing of natural sand-clay mixtures.

In all sand-clay and gypsum construction, thorough mixing and careful proportioning are essential if first class roads are to

FIG. 23.—A well-built sand-clay road about five years old.

result. As the road is opened to traffic it is not a finished product but will require smoothing with the grader or drag at intervals for a year or more. Quite often it will be apparent as time goes on that more sand or clay, as the case may be, is needed, and such should then be added a little at a time until the road becomes smooth and firm.

Not infrequently the ingredients for a sand-clay road are thrown together in a haphazard manner, the mixing being left to be done by traffic and the road receives little care, and in spite of the neglect becomes a fairly good road. The time and expense necessary for the best results are, however, fully justified by the better service the road will give.

Characteristics.—The sand-clay road is resilient, dustless, and will be smooth if properly built. It becomes only slightly muddy

on the surface, is serviceable for moderate traffic, and requires little care after it finally becomes solid. It may be damaged by traffic during long-continued dry weather. The cost ranges from $350 to $1,200 per mile for roads 14 ft. wide, depending as would be expected on the availability of materials and the cost of labor.

EXAMPLES OF GOOD PRACTICE

Kansas[1]

Selecting the Binding Material

In the construction of a sand-clay road it is a difficult problem to select a proper clay for the binding material; laboratory tests will assist in determining what to expect from different clays, but it is much better to check the laboratory test by building only a few miles of road at a time until the practical test demonstrates the worth of the clay. The properties of clay which are of the greatest importance in road construction are plasticity and the property of slaking when they first become wet after having been uncovered. The most plastic of these materials are technically called "ball clays." A lump of such clay immersed in water will usually preserve its form a long time.

Nonslaking clays, although they are very sticky when wet, generally mix readily with water. There are other clays, however, which will immediately fall to pieces when immersed, as a lump of quicklime will do. This is due to the rapid absorption of water in the porous structure of the clay. These are known as slaking clays and are more easily mixed with other materials than the more plastic ball clays, and this is, of course, to their advantage for road building; but, on the other hand, they often have inferior binding powers.

There is still another physical characteristic of clay of great importance in the construction of roads. Many clays shrink when dry. This shrinkage is the measure of their expansion, and expansion renders the sand-clay mixture unstable. When water removed by evaporation is restored to the sand-clay mixture, its entrance is accompanied by a simultaneous expansion which separates the grains of sand. This property is inherent in the clay and cannot be overcome, but by using less clay its destructive action can be modified in a measure. The best kind of clay for this construction is one which slakes easily

[1] W. S. Gearhart, Highway Engineer, Kansas Agricultural College, in *Bulletin* No. 6.

enough to enable the lumps to be readily broken up and which at the same time, without being too plastic, has sufficient binding power to cement the grains of sand and form a smooth impervious road surface.

The available materials should also be tested in order to secure a clay having the least possible shrinkage. The best method is to examine the roads in which this material is found. The best wearing surface of the sand-clay road is obtained when the voids in the sand are entirely filled with a good binding clay. Any excess of clay above the amount required to fill the voids in the sand is a detriment.

Method of Constructing Sand-clay Roads on a Sandy Subsoil

In constructing a sand-clay road on a sandy subsoil, adequate permanent drainage should be provided and the road well crowned. Shoulders should be thrown up to confine the clay as it is deposited. The work should begin at the end of the road nearest the supply of clay and the clay deposited in layers from 6 to 12 in. deep and from 10 to 18 ft. wide, depending upon the volume and kind of traffic to be carried. The large lumps should be broken up while dry and the whole surface smoothed up and 2 to 4 in. of sand placed on top. The sand and the clay should then be thoroughly mixed and puddled with water by plowing and harrowing with a disc harrow. If the water is not available it is well to wait until after a prolonged rain to do the mixing and puddling. Dry mixing has generally been unsuccessful.

If sufficient funds are not available to do the mixing and puddling by machinery it may be left for the traffic to do it. If this method is followed a muddy road will result for some time, however, and it will require probably 2 years to get the road in good condition. When the clay balls, add more sand, and if the surface loosens during the dry weather add more clay, or better, use a clay with good binding power.

Method of Constructing Sand-clay Roads on a Clay Subsoil

A first-class sand-clay road on a clay subsoil can be constructed in the following manner: After the road has been graded

and properly crowned and ample drainage provided, 4 in. of the surface for the width to be treated should be pulverized by plowing and disking and then a layer of sand 6 to 8 in. deep placed upon it and the sand and clay thoroughly mixed, comparatively dry, by plowing and harrowing. Then, after a prolonged rain, puddle the road with a harrow and shape it up while wet; stop traffic if necessary until the surface has become dry, but the road should be thrown open to use as soon as practicable. No sand-clay road is in proper condition when first constructed and it will require careful attention for 2 years. It should be dragged after every rain.

The sand-clay road is more resilient than any ordinary macadam road and generally costs less to construct and maintain than any other except an earth road.

Virginia[1]

The two elements, sand and clay, in the proportion of 75 to 85 per cent. sand and 15 to 24 per cent. clay should be thoroughly mixed until of uniform color. For the best results only sufficient clay to fill the voids between the sand grains should be used, the clay serving as a binder to prevent the sand grains from moving under traffic. On sections of road that are not exposed to the sun and wind, as in a dense woods or deep cut, or on low, boggy sections, a very small percentage of clay is required as water will partially fill the voids between the sand grains. On heavy grades, especially when exposed to the sun and wind, the percentage of clay should be greater than with any other condition.

Placing and Finishing.—The sand-clay mixture should be 8 to 12 in. in thickness at the center and run to a feather edge at ditch line, and 20 to 26 ft. in width, depending on the traffic and local conditions. In roads built as above described the crown is made altogether of the surfacing material.

Unless the surfacing material has been thoroughly mixed before being dumped on the road, the sand and clay should be spread before mixing to roughly conform to the proposed finished cross-section, which should be not less than ¾ in. and not more than 1 in. to the foot, with side ditches somewhat deeper than for macadam.

The sand-clay or soil road should not be considered completed

[1] A. H. Pettigrew, in *Engineering-Contracting,* Mar. 25, 1914.

the first time the surface is put in good shape, as bad sections often develop after the surface has been in shape for as long a period as one year. The real tests for the sand-clay road are the protracted droughts and the long-continued slow, dribbling rains, followed by freezing. The last-mentioned condition is very trying on sand-clay and soil roads and the best constructed road will very probably require some attention after such weather. If the road has been properly constructed, a split-log drag used at the right time will put the surface in good shape.

The use of a roller on this class of road is not necessary, and may be a decided disadvantage. The surface should, like a wound in the flesh, heal from the bottom. It is not practical to lay surfacing in more than two courses, and use of the roller case-hardens the surface, and this case-hardened surface will often carry the traffic until the first protracted wet or dry spell of weather, when it will cut through or break up. While this probably would not be a permanent injury to the road, it would certainly be very inconvenient to the users of the same.

NEBRASKA[1]

Sand-gumbo Roads in Nebraska.—The surfacing material consisted of a good quality of black gumbo and sharp clean sand. The gumbo was spread to a depth of 7½ in. and the sand to a depth of 6 in., both measured loose. The two materials were then mixed by means of plows and harrows and shaped with a steel drag and a road machine. The compacted depth of the finished surface was 8 in. and the crown was ¾ in. per foot. In this work 1,165 cu. yd. of gumbo and 890 cu. yd. of sand were used. The gumbo was hauled approximately 2 miles in slat-bottom dump wagons having a capacity of 1 cu. yd. The sand was hauled a distance of 4,000 ft. in the same wagons. The cost of the wearing surface was as given in the following table.

[1] From *Bulletin* 53, United States Office of Public Roads.

TABLE 9.—COST OF SAND-GUMBO WEARING SURFACE FOR A ROAD IN NEBRASKA

Item	Amount	Unit cost per cubic yard	Unit cost, square yard, wearing surface
Purchase of gumbo pit	$41.35	$0.035	$0.008
Loading gumbo	180 40	0.155	0.034
Hauling gumbo	698.80	0.600	0.131
Spreading gumbo	34.00	0.029	0 006
Loading sand	93 60	0 105	0 018
Hauling sand	299 00	0 336	0 056
Spreading sand	10.60	0 012	0.002
Mixing sand and gumbo	37 20	0 018	0.007
Shaping	4.00	.	0.0025
Rolling	13 60	.	0 001
Miscellaneous	12 60		0 002
Superintendence	37 80	..	0 007
Total	$1,462 95	...	$0 2745

The following is a summary of the cost

	Amount	Unit cost per square yard wearing surface
Earth work	$ 200.20	$0.0375
Wearing surface	1,462.95	0.2745
Total	$1,663.15	$0.3120

CHAPTER VII

GRAVEL ROADS

Ideal Materials.—The ideal gravel for road construction should be hard and durable, should possess good bonding properties and should be reasonably well graded. Any pit gravel, washed gravel, or river gravel may, however, be used in the construction of gravel roads if the proper methods are followed. The roads will not all be equally durable although all will be serviceable. For high-class construction gravel approximating closely the ideal is necessary.

Wearing Qualities.—The hardness and toughness of the stones in the gravel may be determined in the Deval machine in the manner in which similar properties of broken stone are determined. The results are neither as uiform nor as significant as for broken stone, but serve as a reasonably accurate measure of the value of the material. Quite often individual stones among the lot tested are of some partially disintegrated material and lose a disproportionate amount during the test. A gravel containing a few stones of this kind would probably wear better in the road than the test would indicate. Again a selected sample would often show better in the test than the material from which it was taken would under traffic in a road.

A careful examination of the gravel in the pit will usually indicate, in a general way, whether or not it is durable enough for road purposes. If a large proportion of soft or partially disintegrated stones are encountered, the gravel should not be used unless it is very cheap and contains a fair proportion of a good sand and is to be used for what might be termed high-grade sand-clay construction. Fig. 24 shows the face of a typical gravel deposit.

Bonding Properties.—The bonding element in gravel is usually clay or loam but may be of mineral composition such as ironoxide. The bonding qualities of some gravels are due partly to the angular shape of the particles and only partly to the clay. The amount of clay in the gravel should not exceed about 20 per

cent. but a considerable range in clay content is found in gravels of good bonding properties. The kind of clay and the nature of the gravel with which it is mixed varies so much in the different deposits, that in many cases only service tests will reveal the behavior of the material under traffic.

FIG. 24.—Face of a bank gravel deposit.

Grading.—The gravels should be fairly well graded from a size that will pass a 2-in. screen down to the fine clay and the better it is graded the more stable the road will be. Not more than 80 per cent. nor less than 60 per cent. should pass a 1½-in. screen.

Selection of Gravel.—Knowing the desirable characteristics of an ideal gravel to be used for road purposes, the one nearest the ideal may be chosen from among those available, or two gravels may be mixed on the work and thus a material produced which will be superior to either used alone. It often happens that gravel

roads must be built from local material which is far from ideal and such gravel can be made into a serviceable road by careful manipulation.

The pit gravels fall into four groups: those that approximate fairly closely the ideal gravel; those that are too coarse; those that are too fine; and those that are deficient in bonding material.

If the gravel is too coarse, the larger pieces may be screened out and thrown aside or crushed and mixed with the material that has passed the screen. It may be desirable in some cases to add sand to increase the amount of fine material and facilitate compacting the gravel in the road.

When gravel is encountered which is too fine, usually no coarse material is available to mix with it. Such a gravel can be used if sufficient clay is present or is added to bond the gravel and the road thus constructed will be much like the sand-clay road in character. It will be dusty in dry weather and somewhat sticky on the surface in wet weather, but will usually be a fairly satisfactory road for moderate traffic.

The gravels which are deficient in bonding material are usually found in stream beds or have been deposited by stream action on bars, but some bank gravels are also of this class. The deficiency in bonding material can be supplied by mixing clay with the gravel after it has been spread on the road. If this is carefully done, excellent roads result because gravels of this class are usually very durable. Limestone screenings are an excellent binder for gravels of this character, particularly if a little clay is also added.

Preparation of Road for Gravel Surface.—Before a gravel surface is placed the road is brought to a suitable grade and cross-section and ample surface and subsurface drainage provided as described in Chapter III. It is unwise if heavy grading has been done to place the gravel surface for a year after the earthwork was done. This will give time for the road to become so thoroughly compacted by traffic as to form a stable foundation for the gravel. If the gravel must be placed immediately after the earthwork is completed, then everything possible should be done to compact the foundation thoroughly. A roller will be of great help if it is available, particularly if the road can be rolled a few days after having been soaked by rains. In this case it is best to place only the lower course of the gravel the first season. This lower course will probably become rutted and uneven as the

foundation settles, but it will become firm and stable after a time, even though uneven.

The surface layer can then be placed and a much more durable road secured than if both layers had been placed at the same time. Even on good foundation there is reason to believe that for best results one-half of the gravel should be placed each season. This, however, is impractical under many systems of administration, and both layers are usually completed under one contract. When such is the case, the lower layer is spread for a part of the distance and rolled, and followed immediately by the placing of the upper layer.

Since the gravel will compact slowly after it is spread, it is important to provide earth shoulders at the sides to hold it in place in the meantime. These shoulders may be formed by bringing in material from the ditches or back slopes with a grader, or they may be formed by plowing a few shallow furrows in the middle of the road and scraping the material thus loosened to the sides to form the shoulders. If the cross-section of the earth road upon which the gravel is to be placed is somewhat flat, the former method will be used, but if the cross-section of the earth road is well rounded up, then the latter will be followed. The shoulders should be straight and true so that the finished road will have a workmanlike appearance.

Width and Thickness of Gravel.—The prevailing width of single-track roads is 10 ft. and of double-track roads 15 or 16 ft. On all well-drained soils a layer of well-packed gravel 8 in. thick is adequate and if the roadway is double-track width the thickness of the layer at the edge may be reduced to 4 or 5 in. The gravel should be placed in two approximately equal layers, perhaps allowing a little more thickness to the lower layer than to the top. It is difficult to say just how much the gravel will shrink while being compacted, but for average conditions a layer 11 in. thick measured after being spread on the road will make a finished road 8 in. thick.

Crown.—On account of the tendency of the gravel road to become uneven and to flatten under traffic it is desirable to construct it with cross-slope of 1 in. per foot. The cross-slope is usually an arc of a circle and the crown of 1 in. per foot would therefore be an average, the actual cross-slope being small near the middle of the road, increasing in rate toward the edge. Since the gravel surface will be somewhat porous for a time,

some storm water will penetrate to the foundation which should therefore be crowned enough to cause the water which reaches

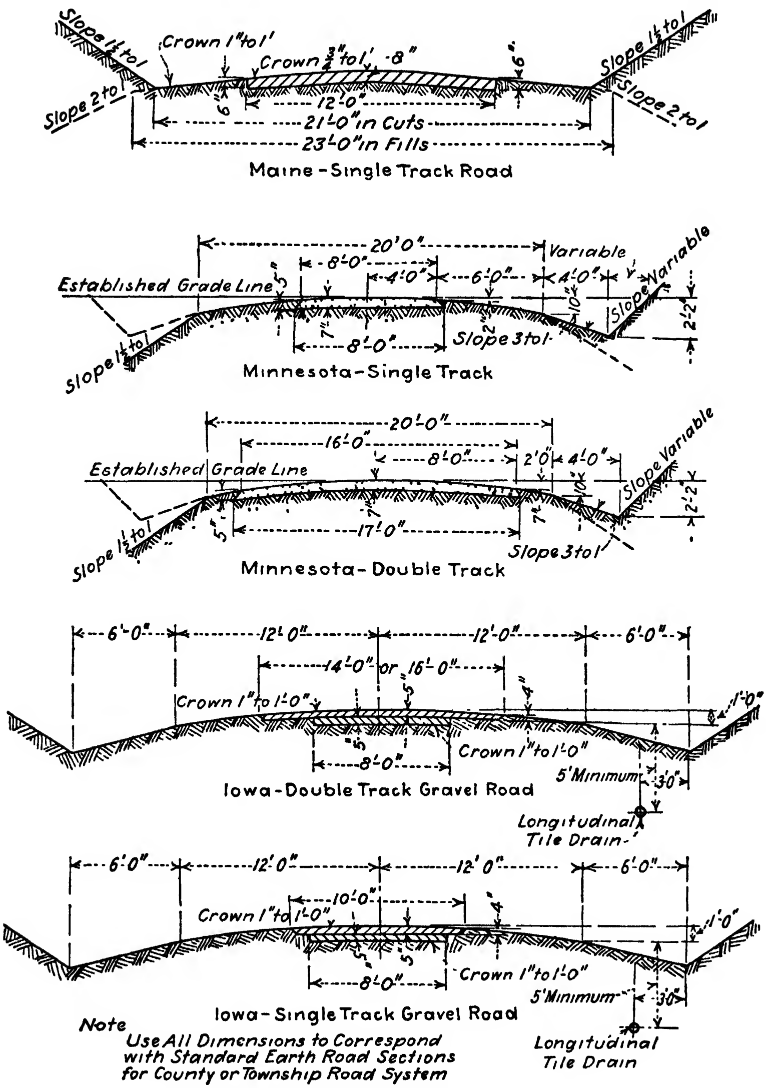


FIG. 25.—Cross-sections for gravel roads.

it to work to the edge of the gravel. It will then gradually soak away in the earth shoulder. If held on the subgrade, it might soften it sufficiently to cause the surface to become

uneven. Fig. 25 shows some typical cross-sections for gravel roads.

Placing the Gravel.—The gravel is dumped on the road in a quantity that will spread to the thickness desired for one course and is then spread with shovels or rakes. In many instances the blade grader is used to spread the gravel and has proven to be a cheap and efficient machine for the purpose. It is nearly always necessary to do a little hand-spreading to finally bring the road to a true and even surface, but the amount of hand work is much reduced if the grader is used first. After the lower layer has been placed it is thoroughly harrowed to mix the materials into a homogeneous mass. It is then opened to traffic for as long a period as possible, or is thoroughly rolled before placing the top course. Many gravels are of such a nature that they do not compact readily under rolling and become firm and dense only after traffic has been on the road for a considerable time. As mentioned before, the best results will be obtained if the lower course is used for a year before the upper course is placed. During the time that the lower course is under traffic it should be patrolled regularly and if ruts and depressions appear they should be filled with gravel.

The top layer of gravel should be placed in the same manner as the lower course but if the lower course has been made single-track width, and additional width of finished road is desired to permit of vehicles passing on the gravel, the top layer may be made wider than the lower. Since the travel on the outer portion will be infrequent, a layer 4 or 5 in. thick at the edge will prove adequate. The gravel along the edges will eventually become more or less mixed with the soil of the side road, forming virtually a sand-clay road along the edge of the gravel.

Considerable care should be used in spreading the gravel so that the surface will be smooth and have a suitable cross-slope.

As was mentioned in connection with the placing of the lower course, rolling assists in compacting the surface with many gravels and with others does little good. In general as serviceable a gravel road can be constructed without a roller as with one, except that traffic will be discommoded during the process. After the road is opened to traffic it must be patrolled regularly for at least 6 months and the ruts and depressions that appear must be filled with gravel.

If very clean gravel such as is obtained by dredging or pump-

ing from river bars is used, it is necessary to add clay to bond the road surface. After the gravel has been spread on the road, it is covered with about 2 in. of clay or loam from along side the road. Most of this clay will shake down among the pebbles as the traffic uses the surface and the road will get out of shape easily. But frequent dragging will restore the shape as fast as it is destroyed by traffic and the road will gradually become solid. A little additional clay may be necessary from time to time during the first 6 months at least on portions of the road. If the surface can be reshaped after about a month of traffic and then covered with about 1 in. of good bonding limestone screen-

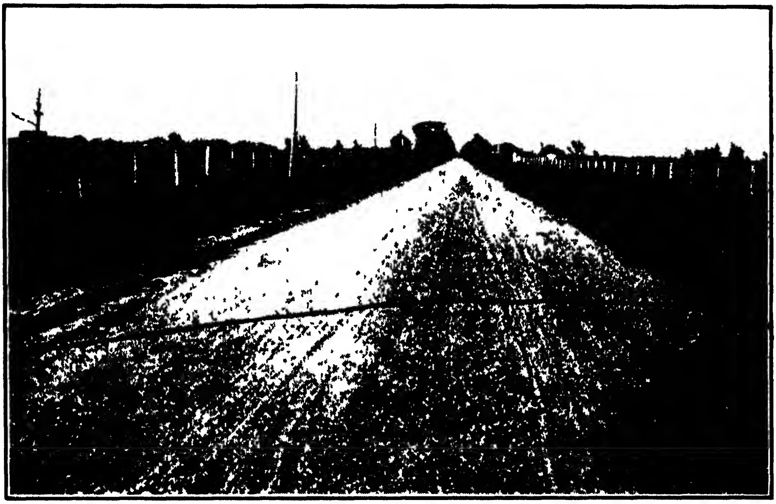


Fig. 26.—A well-built gravel road.

ings, the next rain will cement the surface together into an exceedingly durable road.

A split-log or plank drag is very useful for maintaining the surface during this period, and if the dragging is done carefully after the rains, a smooth, even, durable surface will result, and a comparatively small amount of maintenance work will keep it in good condition.

Characteristics of Gravel Roads.—Gravel roads have a surface that is comfortable to travel, that affords good traction for motor vehicles and that can be easily maintained under normal conditions. It resists the destructive effect of motor traffic better than a broken-stone road, but is apt to be dusty in dry

weather. Usually it is advisable to provide an earth side road for use in dry weather.

The cost of the road varies from $1,500 per mile to $2,500 per mile for a double-track surface.

Maintenance.—The tendency of traffic to keep in one track eventually causes two broad ruts to appear in the surface and when this rut becomes of sufficient depth to cause inconvenience it should be filled with good gravel. Very little good is done if the rut is filled with fine material because traffic will quickly displace it. Nor is it advisable to fill the rut when the road is dry because the material added will not bond with the old surface. But if the new material is added after a rainy period of some duration, the old surface will be soft enough that the new material will bond with it. The new material should be added in excess of that necessary to fill the rut so that when it has been thoroughly compacted, there will be no depression. The traffic will avoid the strip of new gravel at first so that it will come into general use only gradually.

With intelligent maintenance the gravel road will last indefinitely and be satisfactory for moderate traffic of a mixed character, that is up to 200 vehicles per day of which not more than two-thirds are motor-driven.

GRAVEL-COATED EARTH ROADS

In a few sections of the United States there is found a black silty clay soil that bears up well under heavy loads but is very sticky in wet weather. If the surface is coated with just enough gravel to prevent the soil becoming sticky, a satisfactory road is obtained. The following is a brief description of the method of surfacing such roads as followed in Polk County, Minnesota.

A well-drained and well-crowned dirt road is necessary for a foundation. The road should be well packed and should have been traveled for several years, and should be at least 20 ft. wide on top, and should have a crown from 6 in. to 1 ft.

The gravel is hauled and placed along the center of the road at the rate of about 1 cu. yd. to every 10 ft. or length of wagon box. This amounts to about 530 cu. yd. per mile.

The gravel is then spread with a blade machine, with shovels, or left to spread itself and be beaten in by traffic. It becomes a smooth hard, well-beaten road in 2 or 3 months. This coat is

left on the road from 3 to 6 years or till clay begins to show in the surface and the road becomes rough, then a second coat is put on in the same manner as the first coat.

In the above method, earth shoulders are not necessary. They only increase the cost of construction and prevent the top of the road from draining off properly.

Most of the gravel is hauled in the winter after the ground freezes since teams can be got in abundance at that time of the year and at a lower price than at any other season. In the winter the price per cubic yard per mile for hauling will range from 12½ to 20 cts. Gravel generally costs from 10 to 15 cts. per cubic yard in the pit.

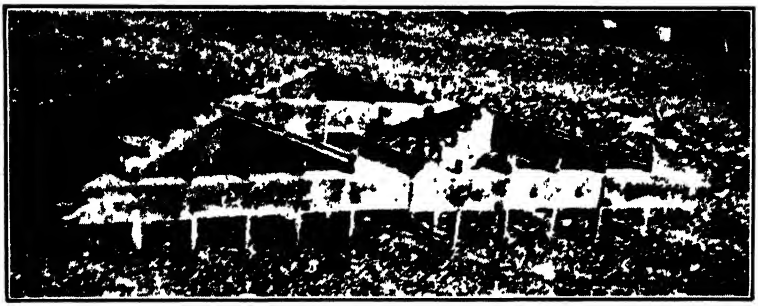


Fig. 27.—Harrow suitable for gravel road construction.

EXAMPLES OF GOOD PRACTICE[1]

Gravel

Gravel shall be furnished by the contractor from banks approved by the engineer and shall be of a quality satisfactory to the engineer. In general, it shall consist of hard, sound, durable stones of various sizes, ranging from pea stone to a maximum size of 3¼ in. The quality of the binding material shall be determined by the engineer. The amount of binder contained in the gravel shall be not less than 15 per cent. nor more than 25 per cent. and in case the fine material which occurs in the bank is deficient or is not suitable as a binder the contractor will furnish suitable material and spread a layer of such material on each course, mixing and rolling the same, as directed by the engineer until it is thoroughly bonded. Gravel shall be spread in either two or three courses. The roller shall weigh at least

[1] Abstracted from Maine specifications for 1914.

10 tons. Any depressions shall be filled and compacted, at the time they appear, with the same material which is being used.

Two-course Road

Whenever the smaller sizes of stone predominate, the bottom course shall have a thickness of 4 in. after rolling. This course shall be bonded with fine material before the second course is applied. The second, or top course shall be similar to the bottom course and shall have the same thickness. It shall be bonded with fine material until a firm, hard, smooth surface is produced. The rolling of each course shall be done while the gravel is wet, using a sprinkler if so ordered by the engineer.

Three-course Road

Whenever the larger sizes of stone predominate, the bottom course shall have a thickness of 3 in. after rolling. The second course shall be of the same kind of material and of the same thickness. The top course shall have a thickness of 2 in. after rolling, and contain stones not larger than $1\frac{1}{2}$ in. in size. Each course shall be thoroughly bonded with fine material by mixing, rolling and sprinkling until a firm, hard, smooth, surface is produced.

Spreading

Spreading wagons may be used when approved by the engineer. When dump carts are used, the gravel shall be dumped upon platforms or upon the ground on the sides and then spread uniformly over the surface to be built. It may be also spread with shovels from the carts. The contractor shall deposit where directed by the engineer, along or near the edge of the road in piles neatly formed and approximately 500 ft. apart, 5 cu. yd. of gravel for use in maintenance of the road. Gravel surface when finished shall conform to the lines and grades given by the engineer in accordance with plans and specifications. No allowance will be made for material which may be driven into the subgrade by rolling.

Payment for gravel road will be made per cubic yard compacted into place in accordance with the thickness specified on plans.

Gravel for maintenance shall be paid for at the price bid per cubic yard, but measured in the wagon at point of delivery on the road.

Gravel Bed and Shoulders.—After the road has been graded, the gravel bed shall be formed in the central part of the road grade as follows: Shoulders of firm earth or other suitable material shall be placed on each side of the gravel bed not less than 9 ft. apart or such greater distance as may be required to retain the width of gravel specified. The shoulders shall extend to the side ditches or gutters at the same grade and curvature as required for the finished road. Where the road grade is high, the shoulders may be formed by moving earth from the center of the present road grade to the sides, or, if the grade is low, by crowning the present road grade by scraping earth from the sides toward the center, or if sufficient suitable material cannot be had along the roadway, it shall be brought from other places along the line of work.

Rolling Subgrade.—After the shoulders and gravel bed have been formed as above described the whole roadway shall be rolled until no more compacting is possible. The hollows developed by this rolling shall be filled with suitable material under the direction of the officers in charge and the roadway again rolled and left in solid and firm condition everywhere parallel to the finished roadway, the metal bed being 8 in. below the finished grade and having the same crown. In deep mealy sand, where rolling is impracticable when subgrade is shaped, marsh hay, wet straw, or fine brush shall be laid on subgrade to prevent the first course of gravel from mixing with the sand.

First Course of Gravel.—After the road has been graded and rolled in the manner above described, a layer of gravel shall be spread on the prepared bed to such uniform thickness as to be not less than 5 in. deep after compacting, 6 in. deep, loose measure. The gravel for this course shall consist of good, clean bank gravel, not less than 60 per cent. by weight, a larger per cent. if possible, of which shall be pebbles that will be retained on a screen of ⅛-in. mesh and pass through a screen of 2½-in. mesh. If clay gravel is used, it should contain only clay enough to coat the pebbles, no free lumps. In no case should the clay exceed 10 per cent. of the mass, for clay makes mud and adds no wearing qualities. The gravel course shall then be harrowed with a spike-tooth harrow and rolled until no further compacting is possible.

The rolling must be done only when the road has been well wetted by sprinkling or after rains. Any hollows that may develop in the gravel during the process of rolling shall be filled with the same kind of gravel and the rolling continued until the surface is uniformly smooth and hard and everywhere parallel to, and 3 in. below the surface of the finished road. The crown can be preserved during construction by the occasional use of the grader or other suitable floating tools. Ruts formed by hauling over the gravel shall be kept filled by using the harrow twice or more every day preferably just before quitting time both noon and night.

Second Course of Gravel.—The gravel for the second course shall consist of good, clean bank gravel, 60 per cent. by weight, a larger per cent. if possible, or which shall be pebbles that will be retained on a screen of ⅛-in. mesh and will pass through a screen of 1½-in. mesh. Other requirements for gravel in this course are the same as specified for gravel in the first course. This gravel shall be spread on the road to such uniform thickness as to be not less than 3 in. deep after compacting, 4 in. loose measure, after which it shall be harrowed and rolled in the same manner as prescribed for the first course. Any depressions that may be formed during the rolling shall be filled with the kind of gravel prescribed for the second course and the road re-rolled until the surface is uniformly smooth and hard and everywhere conforms to the proposed grade and cross-section of the road.

Manner of Rolling.—Rolling shall be done only when the gravel has been thoroughly wetted by sprinkling or recent rains, and shall at all times begin at the sides, rolling lengthwise of the road, but gradually working toward the center. In the final rolling the whole surface of the roadway, including the shoulders, shall be rolled from ditch to ditch and the whole road grade left in such perfect condition that water will flow without obstruction to the side ditches. Rolling may be done with a power roller, a heavy horse roller or a traction engine followed by a weighted field roller, if one of suitable strength to bear weighting to 3 or more tons can be obtained.

With any kind of a roller the spike-tooth harrow, preferably of the lever type, should be used as long as the teeth will penetrate the surface.

New Hampshire[1]

The economic value of gravel roads is such that they should constitute four-fifths of all the roads of a state. By "gravel" I do not necessarily mean a combination of sand and water-washed stone, but any combination of material which contains not less than 60 per cent. of metal in shape and size so that it need not be crushed, whether the binder be true sand, clay or marl.

If the binder is of the latter, it must contain a larger percentage of metal than if composed of either sand or clay. To me, gravel means an aggregate containing either a stone which from its own disintegration will form a binder or one to which must be added some material which is adhesive in wet weather and in drying forms a binding shell.

Construction

In most gravel pits there is stone too large to use in the surfacing but which serves well as a foundation either on sand or in wet clay holes. Telford is not absolutely essential under gravel, if it is used, the stones should be laid with some regularity. Stones as large as 3 in. may be used in the bottom course. The crown of the subgrade should be 1 in. to the foot.

Surfacing may be accomplished by building the shoulders of other material and rolling the gravel 8 in. deep over the metalled surface of the road. I prefer to leave the rough grading with a crown of 3 in. to 10½ ft. (most of the roads we build are 21 ft. wide) and to give the gravel 10½ in. in the center and 3 in. on the outside edge of the road. This reduces the average thickness of the metal but gives a gravel shoulder which is invaluable in the maintenance. It also gives a 10-in. depth for the 5-ft. strip in the center upon which the major portion of the travel comes.

The gravel should be laid in two courses. By the first method this affords proper compactness; in the second it is not so imperative, provided the gravel is self-binding and the load is dumped far enough ahead so that it must be completely forked and shoveled over. Where laid in one course it is very easy to spread the gravel so that the larger stones are all in the bottom

[1] From a paper delivered at the Third American Road Congress by S. Percy Hooker, State Superintendent of Highways.

of the road, keeping ahead of the work in this way and leaving the surface composed of the finer material.

If a binder consisting of clay or marl is to be used, two courses besides the binder should be laid. It is advisable to work the clay course thoroughly through the top surface with a harrow.

Frequently enough rain falls to allow the building of the road without the use of a sprinkler. This summer has been extremely dry, however, and for a considerable time after completion the roads upon which no water has been used have failed to "come together." I find, however, that a good soaking rain will compact a soft road readily, and where sprinkling is expensive it is wiser to build without it.

Cost

The cost of gravel roads will vary to a greater degree than that of either bituminous or water-bound macadam. The pit price of the gravel may be only 5 cts. per cubic yard; its cost is fixed by the average haul. With the material very near, the cost of gravel construction may not exceed $1,600 a mile, while with a 2-mile haul it may reach $3,500. Assuming grading and drainage expenses to be $1,200 per mile, the total cost per mile varies from $2,800 to $4,800. The average of all the gravel roads built in New Hampshire has approximated $3,900. It must be remembered that many of these roads are in remote sections, where the cost of the more expensive road would be far higher than the average in states where the railroad facilities are better.

CHAPTER VIII

WATER-BOUND MACADAM ROADS AND PAVEMENTS

Road surfaces constructed of broken stone cemented into a solid mass by means of stone dust and water are known as water-bound macadam. The surface thus constructed depends for its stability upon the somewhat weak but effective cementing property that is possessed by the dust from many kinds of rock. The water-bound macadam surface made with good stone will be sufficiently stable to carry loads of considerable weight, but the integrity of the surface depends upon the excellence of the cementing properties of the stone dust used.

When the surface layer is cemented together by means of a bituminous material which has been poured into the openings between the stones the surface is known as penetration bituminous macadam.

Materials.—Limestone, granite, and the various kinds of rocks designated as trap are the principal water-bound macadam materials, limestone and trap being employed much more extensively than the other kinds.

Slag, shells, burnt shale, low-grade iron ore, and sandstone are occasionally utilized, but cannot be considered of wide importance as macadam materials.

Quality of Rock.—A macadam road is subjected to the constant abrasion of steel-tired vehicles, which tends to grind off particles from the surface stones. In order to resist this action the stone must possess the quality of *hardness.*

The surface is also subjected to constant pounding from horses hoofs and from the jar of steel-tired vehicles. The tendency of these forces is to chip off fragments from the rocks or to break the rocks into smaller pieces. The quality of the rock that enables it to resist destruction in this manner is known as *toughness.*

The individual pieces of stone in the surface of the road are constantly being moved slightly in the mass, due to distortion of the surface under heavy loads. This causes the pieces of stone to rub and grind against each other, and to resist this

effect the stone must have good *wearing properties.* The abrasion test which determines the wearing property is also to a degree a measure to the ability of the stone to resist the grinding action of traffic and shock, so that the test is really a combined hardness and toughness test.

The individual pieces that make up the surface of the road are held in place partly by the mechanical interlocking induced by the rolling and partly by the cementing action of the stone dust or screenings that fills the interstices between the larger stones. It is, therefore, exceedingly important that the stone have good *cementing properties.*

FIG. 28.—A poorly construction macadam which is raveling.

Since the surface stones are held in place by the cementing action of the screenings and since these screenings will blow away, will be whipped off the surface and out of the spaces between the stones by automobiles and will be washed away by storms, it is necessary for this bonding material to be replaced from some source. If the stone wears fast enough, the dust thus made will serve to replace that which is removed and therefore the surface will remain in better condition under mixed traffic if the stone wears fast enough to furnish the right amount of dust. Just what grade is best for any particular road will depend upon the traffic.

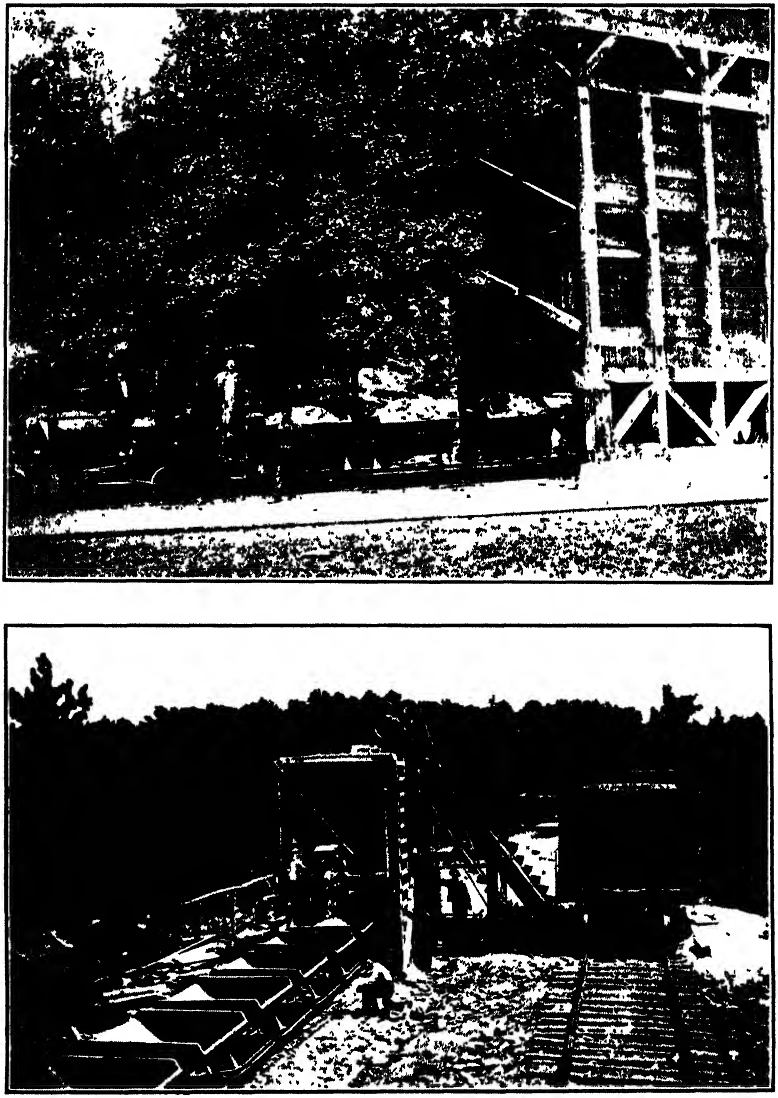
Size of Stone in Surface Layer.—The maximum size of stone is that size which is just strong enough to carry the loads on the

road without crushing. A tough stone need not, therefore, be as large as one low in this property. The size is further limited, however, when in order to secure a stone large enough to withstand traffic, a size is reached where the stone will tip in the surface as a wheel rolls over it. While some engineers permit the use of a stone passing a 3-in. ring, it is probable that a size passing a 2½-in. ring is about the largest that can be recommended. If the stone is high in the property of toughness the size need not be so great. As a general principle it may be said that if the French coefficient of wear exceeds 12, the size for the surface layer may be from 1½ in. down to ¼ in., and the size from ¼ in. down may be utilized as screenings for bonding the surface, but for motor roads it is better to use 2-in. or 2½-in. for the upper course. If the stone has a coefficient of wear less than 12, the size may be from 2½ in. down to about ½ in. and the screenings may be from ½ in. down. Probably the lower limit of size for this stone could be either 1 in. or ¾ in. without materially affecting the construction, but the screenings should not be run coarser than ½ in. The trend of current practice is toward the use of 2½-in. stone in the wearing course.

Size of Stone for Lower Course.—It is not so important to have the stone for the lower course of any particular size so long as it is convenient to place and roll. Good serviceable roads have been built with the lower course made from screenings ½ in. down, but this cannot be recommended as good practice. Any size obtainable up to that which passes a 3-in. ring will serve. The lower course is generally made of a stone larger in size than that which composes the upper course because of the economy in cost of crushing. Not infrequently, however, where the upper course is made of stone ranging from 2½ in. down to about ¾ in., the same size is also used for the lower course.

Size of Stone for Telford Foundation.—The requirements as to the permissible size of stone for Telford foundation are not very rigid. A size that can be readily handled by one man is suitable. One dimension ought to be within 1 in. of the specified thickness of the foundation which may be 6 or 8 in., the width as set is from 5 in. to 1 ft. and the length from 8 to 15 in. The essential requirement is that the pieces can be readily handled, and that they conveniently lay up to the required thickness of course. If too large, the stone will not lock together so as to

be stable under rolling. The larger pieces are "chinked" with spalls so as to hold them firmly in place.



Courtesy O. and A. Koppel Co.

FIG. 29.—Transferring crushed stone to industrial railway.

Crusher Run Stone.—Stone is sometimes taken directly from the crusher and placed on a road. Since the screenings are

mixed with the stone, it may be compacted by rolling or by traffic and will bond into a fairly stable surface. Such a method of construction is suitable only for light-traffic roads, and the surface is not likely to wear evenly.

CONSTRUCTION OF THE SURFACE

It will readily be seen that a macadam surface cannot distribute the load it carries over a very great area of surface. It is commonly assumed that the load is carried to the foundation on 45° lines from the area of application of the wheel or other load. Whether or not this is true, it has been shown by unlimited examples of successful construction that any ordinary soil, when well drained, will carry all normal loads if the macadam is made 8 in. thick.

Exceptions must be made to those soils that are of seepy or peaty nature, and are impossible of adequate drainage. Here the Telford type of foundation would be used.

The roadbed is, therefore, prepared by constructing the necessary side ditches and placing suitable under-drainage as in building a good earth road. The results will be more certain if such work could be done some months prior to the placing of the macadam, a fact that was discussed in connection with gravel roads.

Thickness of Macadam.—For roads constructed on an earth foundation of ordinary clay or loam the thickness after rolling is 8 to 10 in., but the 8-in. thickness is more common. If the foundation is of gravel, deep sand or other equally stable material, the thickness may be reduced to 6 in. It is doubtful if a macadam surface will do at all if a thickness greater than 10 in. is necessary for stability. The thickness given is in each case that which is obtained after thorough rolling which is about 80 per cent. of the thickness of the loose material.

A roller will not compress properly more than about 6 in. of loose stone; therefore it is common practice to place the material in two approximately equal layers, rolling the lower course thoroughly before the upper is spread.

When the Telford type of lower course is employed, its thickness is usually about 6 in., but may be as great as 8 in. The Telford base is carefully placed by hand and all chinks between the stones filled with spalls, gravel, or crushed stone and then rolled with a 15-ton roller.

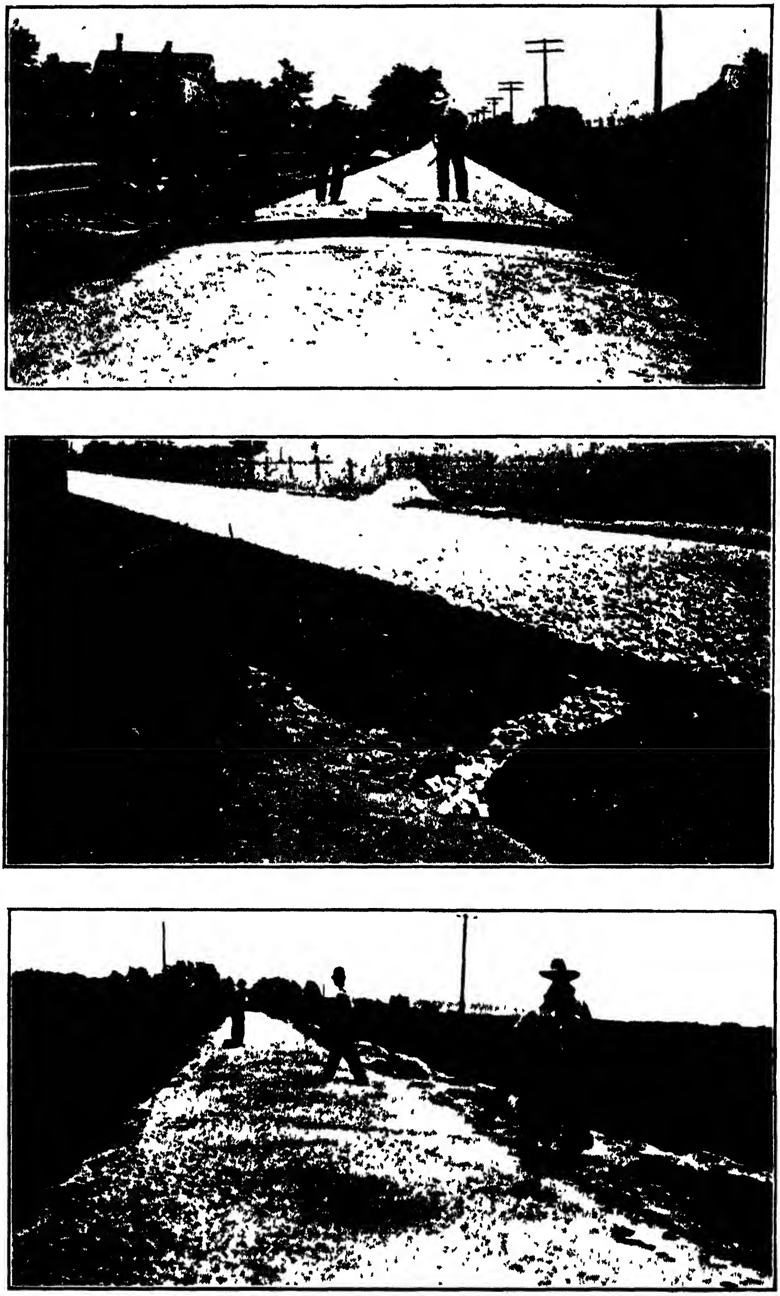


FIG. 30.—Macadam surfaces under construction.

The upper layer for a Telford macadam is about 3 in. thick after it has been rolled.

Quantity of Stone Required.—A macadam surface after rolling requires 27 cu. yd. of stone per 100 ft. of road 9 ft. wide, to which must be added 3 cu. yd. of screening if the upper course only is bonded, and 5 cu. yd. if both courses are bonded. Pavements of other widths and thicknesses may be computed on a basis of a shrinkage of 20 per cent. in the layer of stone during rolling. The quantity of screenings required to bond a layer of stone is about 20 per cent. of the volume of the layer. These quantities hold true for most materials within the limits required for estimates, but will inevitably vary slightly with the size of stone, fineness of screenings and actual density of layer after rolling.

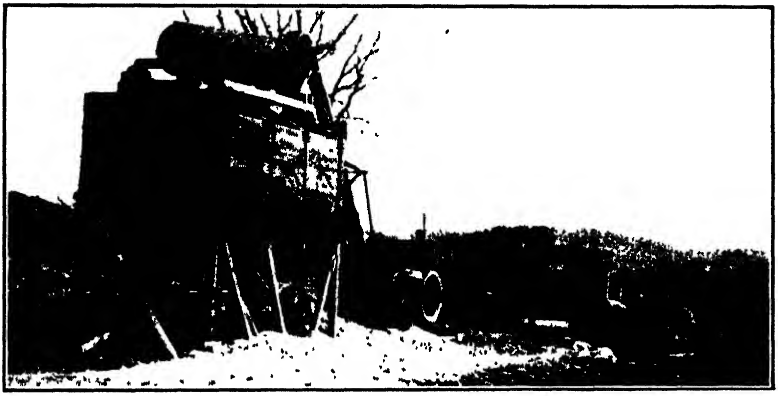


Fig. 31.—A portable stone crushing plant.

Roadbed and Shoulders.—It is imperative that the broken stone be placed between substantial berms or shoulders of earth so that when rolled it will be compacted, not merely spread out. The earth shoulders may be formed by removing the earth from the middle of the road for the required width and grading it out to the sides, thus forming a trench for the stone, and this method is followed when the road to be surfaced is already well shaped up and has the requisite cross-slope.

If the road to be improved lacks the cross-slope or crown necessary for good drainage the shoulders are formed by drawing material from the sides of the road and the ditches. The shoulders thus obtained will be loose and will require thorough rolling prior to placing the stone to insure that they will not spread out when the stone is rolled.

It not infrequently happens that both methods of forming shoulders will be necessary on adjacent sections of a road, on

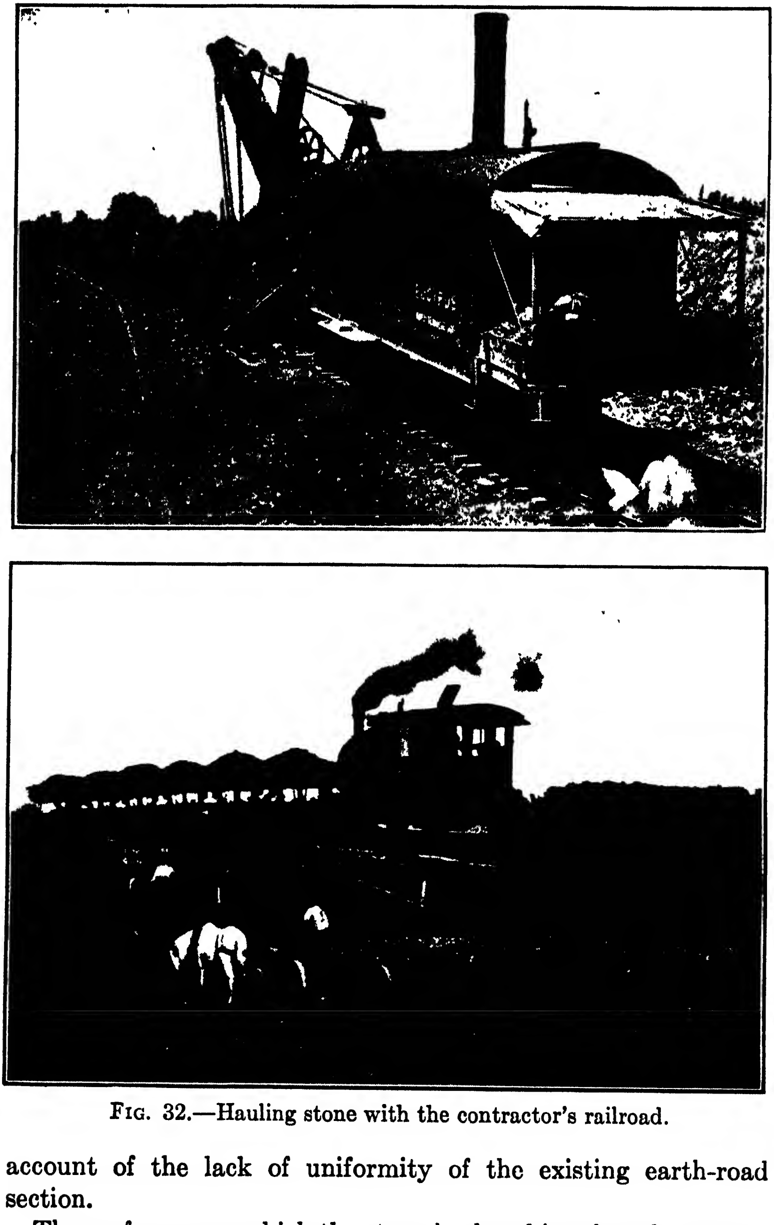


FIG. 32.—Hauling stone with the contractor's railroad.

account of the lack of uniformity of the existing earth-road section.

The surface upon which the stone is placed is referred to as the

subgrade, and usually is made with a convex cross-section. This is desirable for any kind of hard surface that is even slightly porous so that there is a possibility that some water may soak through to the subgrade. When the subgrade is crowned such water will work to the edge and soak away into the shoulder or be conducted away through broken-stone drains.

If, as is generally the case, the amount of crown given to the hard surface exceeds the difference in thickness at the middle and at the edge, this also necessitates a crown in the subgrade.

The subgrade must be shaped with care so that no uneven places exist because they will either reduce or increase the thickness of the macadam depending upon whether they are above or below grade.

Since the stability of the surface depends to a large measure upon the solidity of the subgrade, it is rolled thoroughly. If soft and yielding places are encountered, they are dug out and good material substituted, or, if ground water is encountered, the necessary under-drainage is put in to remove the water and permit the proper compacting of the earth.

Placing the Stone.—If the Telford base is employed, it is placed and rolled as previously described, the stones being carefully set by hand and the spalls and smaller pieces being wedged into the openings between the irregular larger pieces. The whole is then covered with a thin layer of gravel or broken stone and is rolled thoroughly.

When the lower course is of broken stone and is spread by hand, the loads of stone are dumped in such a manner as to be convenient for spreading and the stone then spread by means of ballast rakes.

The thickness is gaged in one method by means of cubes of wood of a size equal to the thickness of the course of stone. These are placed before the load is dumped, and the material is raked down until even with the tops of the blocks. They are then taken out and placed in position for the next load. This method is impractical if the material cannot be spread as rapidly as it is hauled.

In another method the thickness is gaged by means of iron pins set with the top at the proper height to gage the thickness, but otherwise the method is identical with the one in which the blocks are employed.

When stone is hauled in wagons that are constructed so as

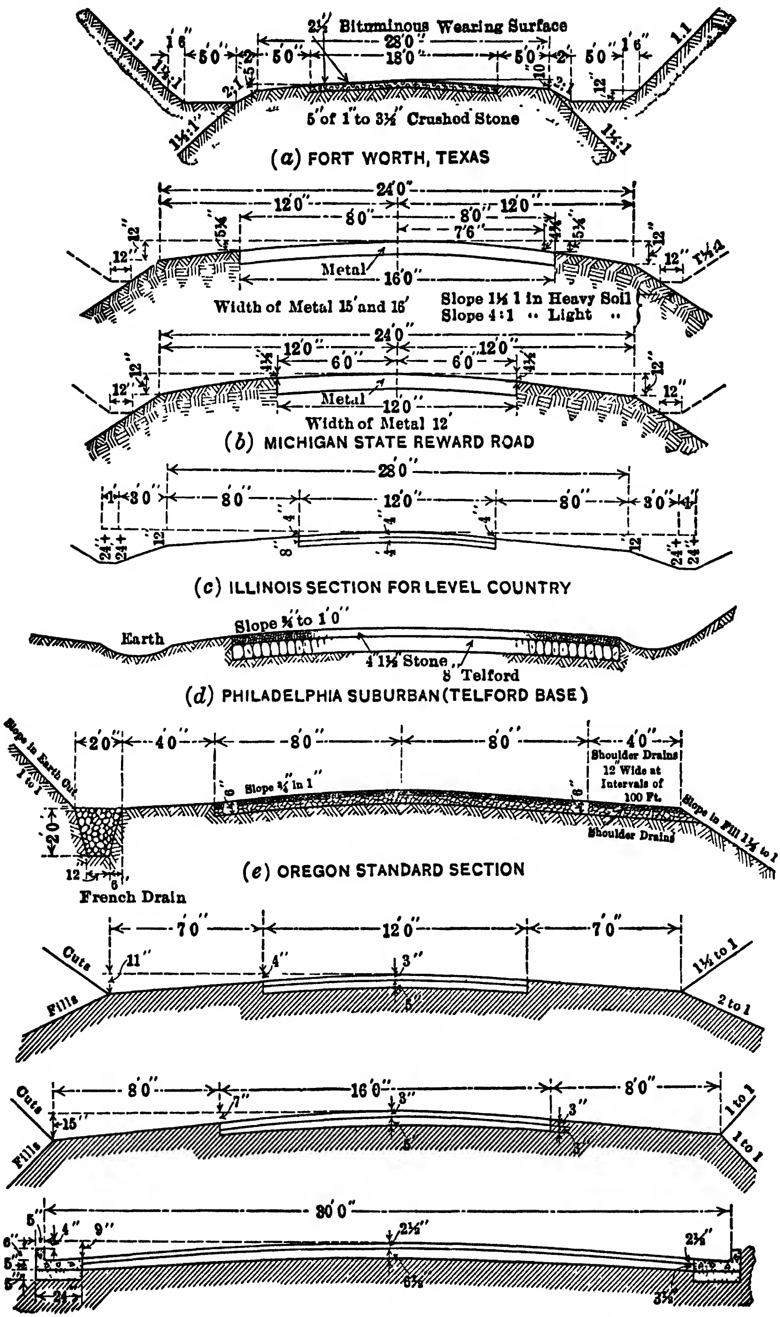


FIG. 33.—Cross-sections for macadam roads.

to spread the material partially when dumped, the driver attempts to move at such a rate as to spread the stone about the proper thickness but the layer must be finally trued up by means of rakes. The larger dump cars that are drawn by tractors are usually equipped in this way and spread the material quite satisfactorily.

Another method that is not infrequently employed utilizes the blade grader for spreading the stone. The loads of stone are dumped at such a distance apart that when spread they will cover the road to the proper thickness. After a number of loads have been dumped they are spread by means of the grader. Usually a little hand work with the rakes is necessary to take out uneven places.

When the loads of stone are dumped the finer material of which

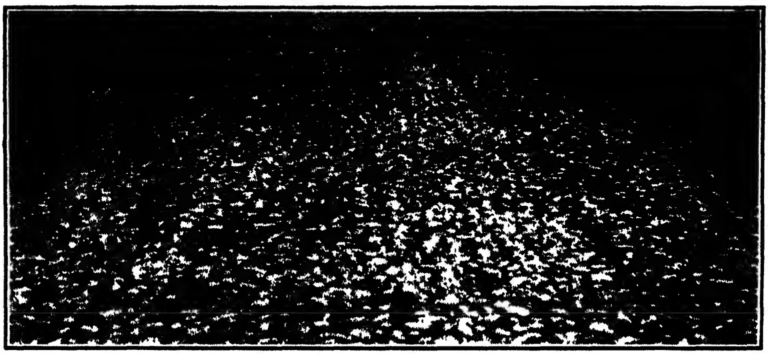


Fig. 34.—A macadam road in need of surfacing.

there is always a certain amount mixed with the coarse, will be deposited in the center of the pile while the coarse will roll to the edges. After the stone is spread the finer material will be in the middle portion of each space covered by one load of stone. This has a tendency to cause unevenness during rolling and is obviated by thorough harrowing, which mixes the finer material with the coarse or causes it to work to the bottom of the layer.

No matter what system of spreading is employed, it will be found advisable to go over the stone with a blade grader just before rolling, to finally smooth the surface. Only a very small amount of stone will be carried along by the grader and this will fill the low places that exist and the blade will drag down the high places.

When stone is being spread in a layer less than about 4 in. thick the spreading must be done by rakes to insure the proper degree of accuracy, and this is particularly true of the upper layer of a road that is to be finished as penetration bituminous macadam. In spreading these thin layers, a templet is used as a guide to the thickness, the ends of the templet being supported on side forms set to the proper grade.

Blind Drains.—During the construction period any rains that come will soak through the unfinished road and the water will collect along the shoulders. To protect against damage at this time, blind drains which are merely trenches sufficiently deep to permit the water to run freely from the subgrade are dug and are partially filled with coarse broken stone which is covered with earth to the level of the shoulder. The stone is generally put in them when the lower course is placed. These drains are spaced about 50 ft. apart on each side of the road but may be closer together in the low places in the road and be omitted near the hilltops. On long hills it is desirable to dig every third pair of the lateral drains to a depth of about 10 in. below the subgrade and extend them to meet at the middle of the road. The drains are sloped slightly downhill on grades and are at right angles to the center line elsewhere.

Rolling.—For limestones a roller weighing about 400 lb. per inch of width of roll is used and for trap and similar stones one weighing about 600 lb. per inch of width is employed. On the lower course the rolling begins at the edge of the stone and the roller moves parallel to the edge of the stone and at a speed of about 100 ft. per minute. The machine moves backward and forward, edging in toward the middle at each trip and when the middle is reached the roller is taken to the opposite side of the road and the process repeated. The roller then returns to the side first rolled and this is repeated until the stone is thoroughly compacted. A roller will properly compact and bond about 50 sq. yd. of road surface per hour.

When the stone is thoroughly rolled, each piece will be wedged tightly between its fellows, and will thus be restrained against any lateral displacement. At this stage of the rolling it will be noted that the stones have begun to break under the roller. If the rolling is continued after this stage is reached, the stone will wear and begin to loosen in the surface.

Rolling on the upper course of the macadam road is carried

out as for the lower course except that the rolling begins out on the shoulder about 4 ft. To do this successfully the shoulders

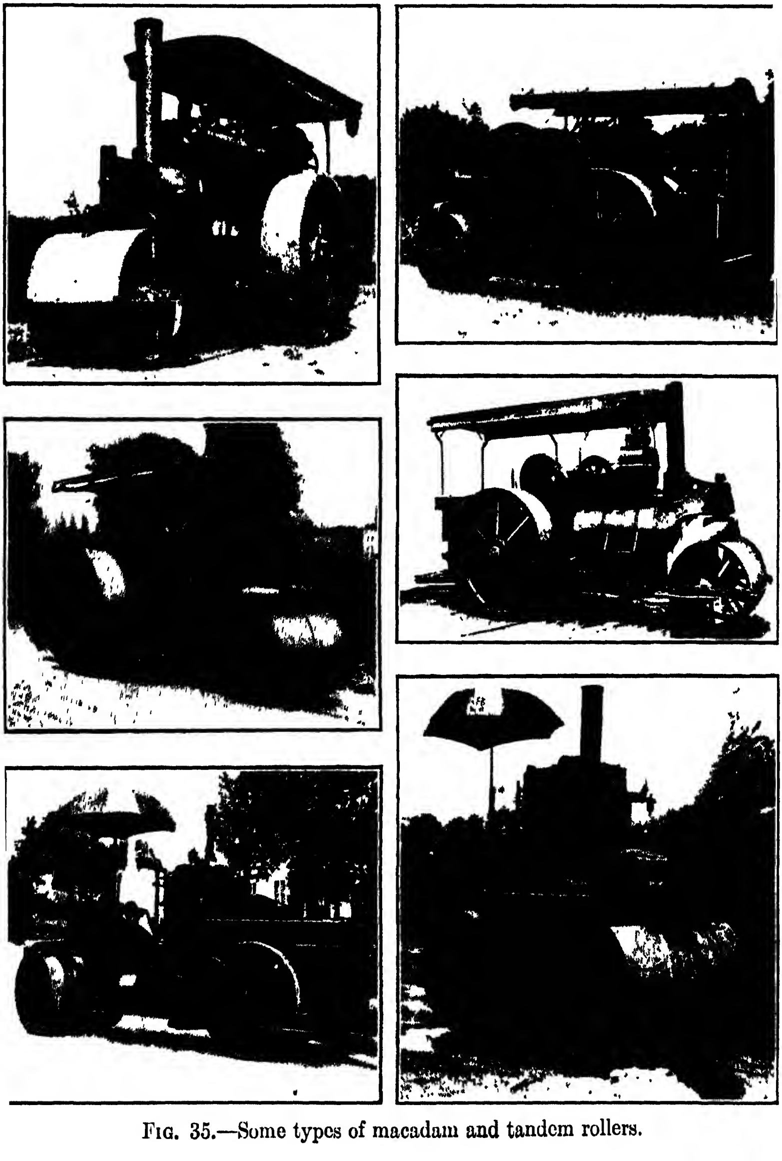


FIG. 35.—Some types of macadam and tandem rollers.

must be trimmed to such a height that they will roll down level with the stone.

During the rolling some uneven places will appear and these are brought up by the addition of a small quantity of stone of the same size as is used in the course. A skilful roller operator will frequently sight along the surface of the macadam to detect uneven places and will so conduct the rolling as to produce a smooth, uniform, tightly keyed surface. Much depends upon the skill and experience of the roller operator and thorough rolling is a vital part of the construction of macadam roads.

Applying Screenings.—After the rolling on the upper course is completed, no vehicles are permitted to drive over it until the screenings have been applied. These are dumped in piles at the side of the macadam and are thrown onto the surface with a sweeping motion of the shovel so that they will not be deposited in piles. The quantity used is that which will just cover the stones. Frequently they are brushed into the surface with fiber brooms. Some engineers then sprinkle the surface lightly and others roll the screenings dry. As the rolling proceeds, bare places will appear and screenings are added until the layer is filled and a small quantity remains on the surface.

Puddling.—When the required quantity of screenings has been spread, the surface is sprinkled and rolled, the roller following immediately behind the sprinkler so that the spray of water falls on or just ahead of the roller. As successive trips are made, the dust on the road and the water form a mortar under the roller which is worked into every crevice in the surface. This operation of *puddling* is exceedingly important if a durable surface is to be constructed.

When puddling is completed the road is closed to all traffic until the screenings set up, which may be for 2 days or a week depending upon the weather. If it is very hot and dry, it is well to sprinkle daily for 2 or 3 days.

After the screenings have set the surface may be rolled again after each rain and the more rolling it gets at such times the better.

Finishing Side Roads.—The shoulders should be neatly trimmed to the proper cross-slope, the back slopes to the ditches and the side slopes on cuts and fills be hand trimmed, and the ditches be properly shaped and cleaned of all loose earth.

Wearing Properties of Stone Roads.—A broken-stone road suffers deterioration from four distinct traffic effects. The first of these is an actual grinding away of the rock by abrasive

action of steel tires. This is quite likely to be confined to a width of about 1 ft. at each wheel track unless the road carries enough traffic to keep the vehicles using the entire width of surface. As a rule the traffic will keep in the middle unless forced to one side. Even well-built roads will have some variation in texture and will not wear uniformly and unevenness will result.

The second of these traffic effects is the removal of the screenings from the surface by automobiles. The wind caused by the motion of the car carries the finer particles away and the shearing action of the tires brushes the larger pieces away. When the surface has been denuded of binding material the wheels begin to loosen the larger stones.

The third effect results from single-horse traffic primarily but is also caused to some extent by two-horse traffic. The pounding of the hoofs on the surface causes the displacement of the stones and to a limited extent breaks up the softer pieces. Single-horse traffic moves so that the horse usually travels in the middle of the macadam where the surface receives little wheel travel to make dust and keep the surface rolled down. Two-horse teams usually travel with each horse about in the wheel track and they do not, therefore, damage the surface as do single-horse vehicles, but have somewhat the same effect.

The fourth effect is due to the elements, such as rains that wash off the screenings and temperature changes that by alternately freezing and thawing the road disintegrate the stones and disturb the foundation. This latter is a minor cause of deterioration on well-drained and well-built roads where good materials have been used.

Maintenance.—The surface may suffer almost entirely from one of the above causes or it may be subjected to all of them simultaneously. The method of maintenance will depend upon just how the surface wears.

If the motor traffic predominates, loss of binder will result, and in order to maintain the surface under such conditions it will be necessary to renew the binder as fast as it is swept off. Screenings or bonding gravel may be used for this purpose, and where possible should be put on while the road is wet.

If the surface wears rapidly, new material must be added from time to time to maintain the thickness. Chuck holes and ruts will appear and these must be filled to maintain the smooth surface.

When new stone is added, the old surface must be loosened to insure that the new surface will unite with the old. Where the area to be patched is small the loosening is done by hand with picks but when extensive resurfacing is necessary, the scarafier or spikes in the roller wheel can be most economically employed. The surface is loosened to a depth of about 4 in., the new material is added and rolled or tamped to place. Screenings are then spread, and the patches or new surface bonded, just as in the construction of a new road.

It is important to keep a broken-stone road in a smooth condition because if a chuck hole starts or a rut appears, it will rapidly increase in size and the comfort and convenience of traffic will be interfered with.

No matter how faithfully a water-bound macadam road is maintained, it will be inadequate to meet the demands of excessive motor traffic unless treated with a bituminous binder to keep the surface intact.

TOOLS AND MACHINERY USED FOR GRAVEL AND MACADAM CONSTRUCTION

Earth-working Tools.—The earthwork incident to hard surfacing is performed with the tools and machinery that have already been described in the chapter on earth-road construction. In addition, many other types of machinery are needed.

Stone Forks.—For unloading coarse crushed stone from cars or loading it from storage piles the stone fork is preferable to shovels. The forks are of various sizes, but one about 14 in. wide with tynes 1 in. apart is very suitable.

Stone Rakes.—A rake of some sort is needed for spreading crushed stone in macadam construction. The type known as the ballast rake has tynes about 6 in. long and five or six in number. It is best to fasten two rakes together "back to back" so as to make a "two-man rake." Two men who become accustomed to this form of rake can handle a large amount of stone with ease.

Wagons for Traction Hauling.—If road-building materials are to be hauled 2 miles or more and the road over which the hauling is to be done is in good condition, heavy wagons drawn by a steam or gasoline tractor are economical. Neither the tractor nor the wagons should be too heavy or they will do serious injury to the road over which they move. The capacity of the

wagons should not exceed 5 cu. yd. and the tractor should not exceed 10 tons in weight. The wagons have adjustable dump bottoms so that material can either be dumped in a pile or spread in a layer on the roadbed. The wagons are arranged with cross-reaches or some such device that will insure their following each other in a single track around turns. In the operation of such outfits weather conditions may reduce the average capacity much below the maximum capacity, especially in territory where the roads over which hauling is done are not improved. On long hauls the capacity of such an outfit is comparatively small because it must travel at a slow pace and hence cannot make many trips per day.

Narrow-gage Dump Cars for Hauling.—When the haul for materials exceeds 2 miles and the amount of material to be hauled is 10,000 cu. yd. or more, a narrow-gage industrial railway is economical, unless the grades exceed 6 per cent. These outfits are made with sectional portable track which can be placed quickly and cheaply and can readily be shipped. The cars have a capacity of 1½ or 2 cu. yd. and are arranged to dump sidewise. About six of these can be drawn by a team or from 20 to 30 by a dinky locomotive. The initial cost of the equipment precludes its use except on large work.

Motor Trucks.—The motor truck for hauling road materials is of recent development and possesses advantages, particularly where the hauling is over improved roads or for delivery over paved streets.

Motor trucks are made with capacities up to 5 cu. yd., and motor trucks of the trailer type are of even greater capacity. These trucks are self-dumping, travel rapidly and when used in connection with some quick loading device will handle large quantities of materials. In recent years they have proven to be especially advantageous for handling the hot mixtures for street pavements such as asphalt and bituminous concrete. They are somewhat uncertain if the hauling is over unimproved roads.

Loading Devices for Materials.—If road materials are being used in small quantities some economy in team hauling can be effected by the loading chute. These chutes are built to be attached to the side of the car and the material is shoveled into them from the car. When an empty wagon arrives, the contents of the chute is dumped into it by merely tripping the door. Thus there is no team time lost while the wagon is being loaded.

If large quantities of road materials are being handled and it is possible to secure railroad cars with dump bottoms, the loading can more economically be done with a bucket elevator. The hopper is constructed under the track and the boot of the elevator placed so that when the car is dumped the contents are fed into the elevator. An outfit of this kind can be installed that will readily load a cubic yard of stone per minute. In order to obviate the delay while the railroad cars are being shifted, a hopper is sometimes built into which the elevator deposits the material. From the hopper the material is let into the wagons through chutes. The cost of loading materials from cars to wagons with this equipment is not much less than for shoveling it by hand, but the loading is much expedited and the necessity for a large force of laborers done away with.

The locomotive crane with clam-shell bucket is also well adapted for loading materials on large work.

Horse-drawn Rollers.—Rollers with a single divided roll and weighing from 4 to 8 tons are employed for compacting the foundation for pavements and for rolling earth roads. This type of roller is drawn by horses or by a tractor. A roller of this type is not very effective on macadam or gravel roads.

Self-propelled Rollers.—Steam- and gasoline-driven rollers are quite general in macadam-road construction and in various kinds of pavement construction. Two types known respectively as macadam rollers and tandem rollers are built. The macadam or three-wheeled roller is designed for compacting embankments, for rolling the foundation for roads and pavements and for the construction of the various kinds of macadam roads. The weight may be from 8 to 20 tons, but for all-around work the 10-ton size is most suitable. The width of the roller varies with the weight but the relative amount of weight on the front and rear rolls should be about the same for all sizes and since the rear roll is larger in diameter than the front, the weight on the rear roll should be about 0.6 of the total weight. The combined width of the two rear rolls should equal the width of the front roll and the path of the rear roll should overlap the path of the front roll about 4 in.

The tandem roller has two divided rolls so arranged that they cover the same path when the machine is in operation. The steering roll is smaller in diameter than the driving roll, but the weight is so distributed that both give about the same compres-

sion to the surface. The tandem roller is built in sizes weighing from 4 to 16 tons, the lighter ones being used for the first rolling on sheet asphalt and bituminous concrete surfaces and for rolling brick pavements before the filler is poured. The heavier sizes are used for rolling embankments and for the final rolling on sheet asphalt and bituminous concrete surfaces.

Scarafiers.—The scarafier is designed for loosening the surface of gravel or macadam roads when repairs are to be made. It consists of two or more hard-steel teeth set in a heavy frame so arranged that the depth to which the teeth penetrate the surface of the road can be adjusted. The scarafier is usually drawn by a tractor or roller and some types are built so that they can be steered independent of the tractor.

Portable Stone-crushing Plants.—For portable crushing outfits the jaw type of crusher is most commonly employed although the gyratory crusher is also made in small sizes. The crushing plant consists of the crusher which will have a capacity of about 10 cu. yd. per hour, and the screening equipment and storage bins. The cylindrical revolving screen is used and is equipped with sections of screen to suit the work in hand. Storage bins are provided with sufficient capacity to take the output between loads so that the plant can run regardless of the regularity of hauling. For portable outfits the ordinary well-driller's rig is used for drilling the ledge for blasting the stone out.

Stationary Crushing Plants.—For the larger installations the gyratory type of crusher is employed and the other machinery and method of operation is much the same as for the smaller plants except as regards size. The drilling is done by means of steam or air drills.

All stone crushers are built in such a way that the size of the product can be changed and the size of the screens can be changed by removing the perforated metal and replacing with another size.

EXAMPLES OF GOOD PRACTICE

Wisconsin[1]

Surfacing—Quantities Required

The following table gives the number of cubic yards of material per mile to make a given loose depth for various widths of roads:

[1] From *Bulletin* No. 4, Wisconsin Highway Commission.

TABLE 10.—QUANTITY OF MATERIAL REQUIRED FOR MACADAM ROADS

Depth of loose material in inches	Width of surfacing				
	9 ft	14 ft	15 ft	16 ft	18 ft.
	Cu. yd	Cu yd	Cu yd	Cu yd	Cu yd
1¼ in. (screenings).	180	280	300	325	367
3 in	440	684	733	782	880
4 in	587	913	979	1,043	1,174
5 in	734	1,141	1,222	1,304	1,468
6 in	880	1,369	1,466	1,565	1,760
Square yards of surface per mile	5,280	8,213	8,800	9,387	10,560

The following table gives the number of linear feet of 9-ft. road a load of a given size should cover for various loose depths. Foremen must compel spreaders to use this table.

TABLE 11.—SHOWING LINEAR FEET OF 9-FT. ROAD FOR VARIOUS SIZES OF LOAD

Weight of load		Size of load	Loose depth in inches			
Granite, pounds	Limestone, pounds		3 in	4 in	5 in	6 in
2,800	2,500	1 cu. yd.	12 ft.	9 0 ft	7 2 ft.	6 0 ft.
3,500	3,125	1¼ cu. yd.	15 ft.	11 25 ft.	9 0 ft.	7.5 ft.
4,200	3,750	1½ cu. yd.	18 ft.	13 5 ft.	10 8 ft.	9 0 ft.
4,900	4,375	1¾ cu. yd	21 ft.	15 75 ft	12 6 ft.	10 5 ft.
5,600	5,000	2 cu. yd.	24 ft.	18 0 ft	14 4 ft.	12 0 ft.
6,300	5,625	2¼ cu yd.	27 ft.	20 25 ft.	16 2 ft.	13 5 ft.
7,000	6,250	2½ cu. yd	30 ft.	22 5 ft.	18 0 ft.	15 0 ft.
7,700	6,875	2¾ cu. yd	33 ft.	24 75 ft.	19.8 ft.	16 5 ft.
8,400	7,500	3 cu. yd.	36 ft.	27 0 ft	21 6 ft.	18 0 ft.

WEIGHTS OF MATERIAL

When buying by weight, to find the amount required, estimate that limestone weighs 2,500 lb. per cubic yard of 27 cu. ft.; granite, disintegrated granite and quartzite 2,800 lb.; unscreened gravel or sand 3,000 lb., and crushed gravel 2,650 lb. Finer-crushed sizes will weigh more than coarse sizes. The above averages the three sizes commonly used if they are dry. Screenings, sand and gravel are often shipped wet and will weigh far in excess of the above.

Spreading

The simplest and most satisfactory way to spread stone accurately to a definite depth is to know how many cubic yards are in a load, and figure from the foregoing table how many feet of road it should cover to the depth required, and to spread it over that many feet and no more or no less. It is much the most convenient to have all loads hauled the same size, in which case the spreader can measure accurately just how to dump each load. To find the capacity in cubic yards of a wagon, multiply the inside length by the width and then by the height (all in feet) and divide by 27.

It takes a good man to make a good spreader. Much of the looks of the road depends upon his work and much of the money available can be wasted by a careless workman who puts on too much material. Check the loose depth of the stone often and see that he is spreading each load to the proper distances so that stone is neither too thick nor too thin.

First Course

(No. 1 stone usually 2 in. to 3½ in. in size, usually spread to a loose depth of 5 in., never more than 6 in. and seldom less than 4 in.)

The first course of rock or gravel can now be dumped on the subgrade and spread to the required thickness with rakes and shovels, after which it is to be rolled until it is packed firm and hard and there is no movement under foot as you walk on it. On very sandy soils, to keep the sand from working up through the stone, place a fair covering of clay, marsh hay, straw, or weeds (good in the order named) before placing any stone. Shoulder trenches should be filled with the No. 1 stone so as to make blind drains. Cover the stone in the trench with sods, grass side down, or with hay or straw to keep dirt from clogging the water course. Care should be used in rolling the first course to keep the roller in the trench and not to overlap the stone and crush the shoulders. Roll from outer edge toward center. Clay or screenings are seldom necessary on the first course. Place about 200 ft. of first course stone before starting to lay No. 2. No. 1 bin does not usually hold this much, but No. 2 stone can be put in the bottom course until the first course is laid 200 ft.

ahead, provided the two sizes are kept in separate strips, laying say the first 125 ft. of No. 1 and then starting with No. 2. Some prefer to pile the No. 2 until the No. 1 is far enough ahead and use it when the end of the work is reached.

Harrowing

Although not much used in Wisconsin, many highway engineers claim that a good stout spike-toothed harrow is a necessity in properly compacting stone and gravel, and that a large part of the rolling of the two first courses can be saved by thorough harrowing after spreading. The Commission will have this method thoroughly tried out on several jobs this summer, and hopes that some of the County Highway Commissioners will also experiment with such harrows.

Second Course

(No. 2 stone, usually ½ in. to 2 in. in size; usually spread to a loose depth of 4 in., never more than 5 in., seldom less than 3 in.)

The second course of stone is now hauled on top of the first and spread evenly to the depth called for. This course is rolled commencing on each outer edge with the rear wheel half on the stone and half on the shoulders and rolling toward the center. The roller should be run over this course a number of times until the stone or gravel is brought to shape and fairly well compacted before screenings or dust is applied. All low places that have shown up should be filled with No. 2 stone and high spots raked down so that the surface presents a smooth even appearance.

Third Course or Screenings

(No. 3 stone, usually from dust to ½ in. in size. Not necessary in pit-run gravel or shale roads.)

Screenings may be hauled at any time after subgrade has been finished. Dump in piles with inner edge about 2 ft. from edge of trench or subgrade. Never dump screenings on the second course. If 1 cu. yd. of 27 cu. ft. is dumped in one place, the centers of piles should be about 30 ft. apart for 9-ft. road or about 18 ft. apart for a 15-ft. road. A cubic yard of screenings under ordinary conditions will cover about 275 sq. ft. of surface.

A cubic yard of screenings bought by weight is not a cubic yard by measure, especially if wet.

Use a square-point dirt shovel to apply screenings. Put them on very thinly with a quick sweeping motion, working from one end of the road toward the other. Keep roller running constantly while putting on the screenings. Repeat this process until all voids between stones are filled. Roll until stone stops moving and the surface is hard, and all second-course stone slightly covered with screenings. It is necessary to bind quartzite or granite with some good cementing material, such as clayey pea gravel or disintegrated granite. If neither of these are available, it is best to use a limestone top course or bind the granite with a bitumen. Clays and limestone screenings have not proven to be satisfactory binding materials for this class of stone. If clay is used, apply it dry a little at a time, and after the voids are well filled and the road is rolled, cover the surface with screenings, preferably with the dust screened out. Don't use too many screenings—just enough to nicely cover the road at all stages is just right. Too many screenings simply allow the road to rut more easily.

Flushing

With the stone covered with screenings the road is ready for water. On clay soils trim down shoulders with road machine before applying water to prevent too much mud at sides. Don't try to finish over 400 ft. of road at one time. It will dry out before you get it soaked. It is customary to finish up each night or every other night the road ready for finishing. If screenings stick to tires, scrape them off or keep tires well wet, or both. Sprinkle road until screenings are thoroughly soaked and tires run clean. When road is wet enough, follow sprinkler with roller. If screenings pick up on roller wheels, stop rolling and apply more water. Keep roller as close to sprinkler as possible. If bare spots or holes appear, put on enough dust to cover them. Sprinkle and roll until water is continually carried along in front of the roller wheels at every point of the road being flushed. Road is then finished. Pit-run gravel roads are flushed in about the same way, but must be very wet when rolled or quite dry. A rainy day is the best time to finish a road.

If the road fails to compact and is spongy under the roller,

the subgrade is too wet. Take the roller off and wait until the road dries out, or if conditions are very bad, dig out the stone and mud underneath, refill with good dry material and surface again. Use tile drain where necessary. Never have more than 600 ft. of unfinished road on your hands. Keep the work compact and finish as you go.

CHAPTER IX

CONCRETE ROADS AND PAVEMENTS

The use of concrete for the wearing surface of the road or pavement is a recent development in the utilization of this material. Concrete has for many years been used as a base for various types of pavements, and as such its function was to distribute the load carried by the pavement surface over sufficient area of the earth subgrade to insure stability. In this use the material is subjected principally to compressive stresses. It is also subjected to temperature stresses but these are generally of no moment since the cracks that result are not numerous enough to affect the stability of the surface.

When concrete is used as a wearing surface it must perform all of the functions required of the concrete foundation and must in addition resist the abrasive action of traffic. Concrete of the composition employed for the pavement base is not well adapted to resist abrasion.

Stresses in Concrete Roads and Pavements.—The stresses to which a concrete road or pavement is subjected are as follows: tension, and compression, due to the distortion of the pavements under loads or to an irregular settlement of the subgrade; tension due to temperature changes and changes in moisture content and abrasion due to the wear and shock of traffic. Of these the last two are undoubtedly the most important.

MATERIALS

Sand.—In proportioning the concrete for a pavement, account must be taken of the character of each of the ingredients, cement, sand, and coarse aggregate. A good grade of Portland cement is assured by requiring that it pass the standard tests for Portland cement adopted by the American Society for Testing Materials. The sand should also be of good quality. It must be clean and must consist of sound particles of quartz or other siliceous materials and must be reasonably well graded from ¼ in. down. It seems to be established that the sand should not

contain to exceed 20 per cent. passing a 50-mesh screen and not more than 5 per cent. that will pass a 100-mesh screen. It ought not to contain to exceed 3 per cent. (dry measure) of clay or loam. In order to test the quality of the sand it is made into briquettes of 1 to 3 mortar and these briquettes tested in comparison with 1 to 3 briquettes made of the same cement and standard Ottawa sand. A suitable sand will make a briquette of at least as great strength as that of the briquettes made of standard Ottawa sand. Unfortunately, there is as yet no generally accepted test for the quality of sand as regards its ability to withstand abrasion. If such a test were extant it would be particularly applicable to sand for concrete for road surfaces.

Coarse Aggregate.—The coarse aggregate should have sufficient strength to withstand abrasion at least as well as the mortar which surrounds it and while no value for the coefficient of wear can be given that will apply to all conditions, it may be taken as a safe general rule that no coarse aggregate should be used having a coefficient of wear of less than 10 as determined by the Deval test described in Chapter V. If the coarse aggregate is somewhat harder than the cement mortar, that is of no particular moment, because when the mortar has worn down even with the stones in the surface it will be protected by them.

It is not only important that the coarse aggregate be made up of a material having a high coefficient of wear but that it should also be of uniform quality so that the surface will wear evenly. Especial precaution should be taken to insure that the coarse aggregate does not contain occasional soft particles. Frequently broken stone or stone screened from bank gravel will contain a percentage of soft pieces. These are quite likely to be found near the surface after the road is finished. If so, they will disintegrate under traffic and climatic action leaving pits in the surface which will rapidly enlarge under the abrasion of steel-tired vehicles.

Size of Coarse Aggregate.—There is no theoretical consideration entering into the selection of the size of the particles of the coarse aggregate other than that the smaller they are the more uniform and smooth the surface will be. Experience has shown rather conclusively that the best results can be obtained if the coarse aggregate used does not exceed a size that will pass a 1½-in. ring, and frequently the size is limited to that which will pass a 1-in. ring.

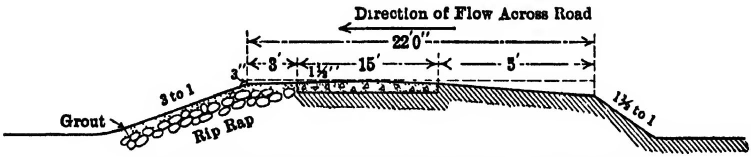
Materials for Two-course Pavements.—When it is impossible at reasonable cost to secure coarse aggregate of the durability required for the wearing surface, the pavement may be constructed in two courses. The lower course is mixed substantially as a pavement base would be but the upper course is constructed of durable aggregates and placed within a few minutes after the lower course has been completed. The composition of the wearing course may be cement, sand and granite, or trap-rock chips; or may be cement and a good grade of coarse sand.

PROPORTIONING CONCRETE

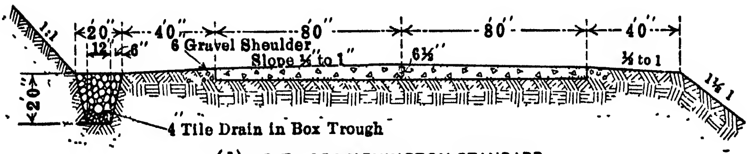
Concrete for a One-course Pavement.—Two factors must be considered in deciding upon the proportions to be used for a pavement. First the ratio of sand to cement that will give a mortar of sufficient strength is determined. This may be 1 part cement to 2 parts sand or it may be 1 part cement to 1½ parts sand. Judgment and experience together with the character of the sand as indicated by the briquette tests will determine the proportion which is required for any known traffic condition. The two proportions mentioned are used to about an equal extent.

The proper proportion of mortar to use with the coarse aggregate is then determined. In deciding this it must be remembered that a smooth, close surface texture is desired and that there must be some excess of mortar so that in placing the concrete the mortar can be flushed to the top readily and will completely fill the voids in the coarse aggregate so as to insure density. Experience indicates that it is desirable to have about 10 per cent. more mortar than is necessary to fill the voids in the coarse aggregate in order to insure dense concrete with plenty of mortar for finishing the surface.

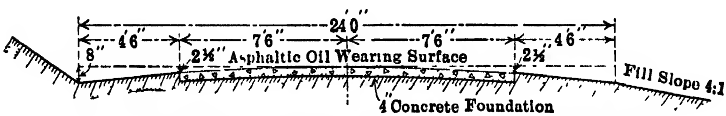
In proportioning the concrete, the exact method is to determine the per cent. of voids in the coarse aggregate and use enough mortar to fill these voids and 10 per cent. in excess. Practical considerations make this impossible in many instances and therefore specifications provide mixtures which will ordinarily accomplish this result but may in some instances give a greater excess of mortar than needed. The mixtures most often specified are 1 part cement to 2 parts sand and 3½ parts coarse aggregate, or 1 part cement, 2 parts sand and 3 parts of coarse aggre-



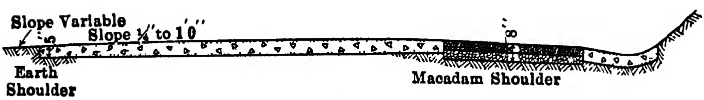
(*a*) WISCONSIN CROSS SECTION FOR OVERFLOW ROADS



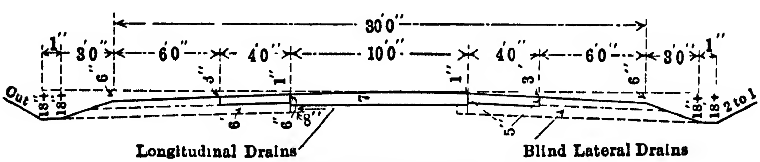
(*b*) STATE OF WASHINGTON STANDARD



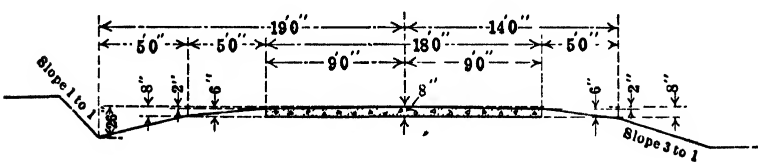
(*c*) CALIFORNIA STATE HIGHWAY FROM HEALDSBURG TO SANTA ROSA



(*d*) PHILADELPHIA SUBURBAN ROAD



(*e*) ILLINOIS SECTION FOR LEVEL COUNTRY



(*f*) STATE OF WISCONSIN (MILWAUKEE COUNTY)

FIG. 36.—Cross-sections for concrete roads.

gate and the latter is probably the most satisfactory for general purposes. These mixtures will give more than 10 per cent. excess of mortar with many kinds of coarse aggregates and where the character of the aggregate is known to be such that a 1-1½-3 or a 1-2-4 mixture will give enough mortar to fill the voids and provide enough excess for finishing, these mixtures are specified. A study of the available aggregates in any locality is necessary before specifying the mixture and if those materials that are satisfactory in quality are variable in grading, the specification must provide good concrete with those having the poorest grading. This will entail some extra cost with those materials that are well graded, but is the only safe course to pursue. As an example let it be supposed that of the available stone that from one source is well graded and upon test is found to contain 35 per cent. voids while another plant furnishes an equally durable stone containing 45 per cent. voids. The specification would then need to provide for a suitable mixture with the stone containing 45 per cent. voids which would therefore give a slight excess of mortar if the stone containing 35 per cent. voids were used.

Cross-section for the Concrete Road.—The concrete road is commonly constructed with a small amount of crown, the usual practice being to make the crown at least equal to one one-hundredth of the width but not greater than one seventy-fifth of the width. These ratios of crown to width are not always adhered to but represent the best practice.

Experience seems to prove that the concrete surface is less likely to crack if placed on a flat subgrade and accordingly for widths up to 20 ft. the subgrade is made flat and the crown is secured by making the thickness of the concrete greater at the middle than at the edge. For heavy traffic the thickness at the middle is usually 8 in. and at the edge about 6 in. For lighter traffic the thickness at the middle is made 7 in. and that at the edge about 5 in. A number of cross-sections are shown in Figs. 36, 37 and 38.

Cross-section for Concrete Pavements.—The rules for crown given above are applied to pavements as well as to roads. On account of the width of a pavement it is impossible to have enough difference in thickness between the middle and edge to secure the proper crown. Consequently the concrete pavement is designed of uniform thickness, which is seldom less than 6 in.

and rarely more than 8 in. This, of course, requires the use of a crowned subgrade. Typical cross-sections for concrete pavements are shown in Fig. 40.

By casting concrete curbs,[1] gutters and pavements as monoliths the cost of highway and suburban road construction has been considerably reduced. Typical cross-sections of the various designs are shown in Fig. 39. Integral curbs add but a small

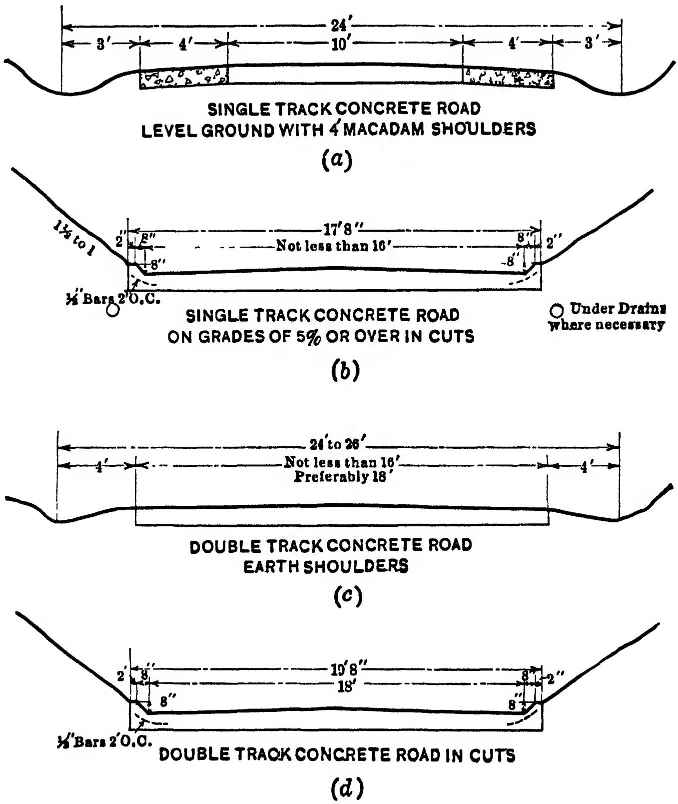


FIG. 37.—Outline cross-sections for special conditions.

amount in yardage of concrete, and the cost, depending on the type, should not be more than one-fifth to one-tenth of the cost of separate curbs. Distributed over the total area of the pavement there is added but a few cents per square yard to the pavement cost.

With reinforcing in the slab it is usual to place the concrete

[1] See *Engineering Record*, Jan. 23, 1915.

in two layers, adding the curb with the second coat. On flat grades the curb height varies between inlets from 2 to 8 in. On streets having sufficient longitudinal slope to insure good drainage the curb height is made 6 in. and even as low as 3 in.

Where the pavement is laid in one course, some form of curved gutter is used. The strike board is then cut away at the end to give the proper shape.

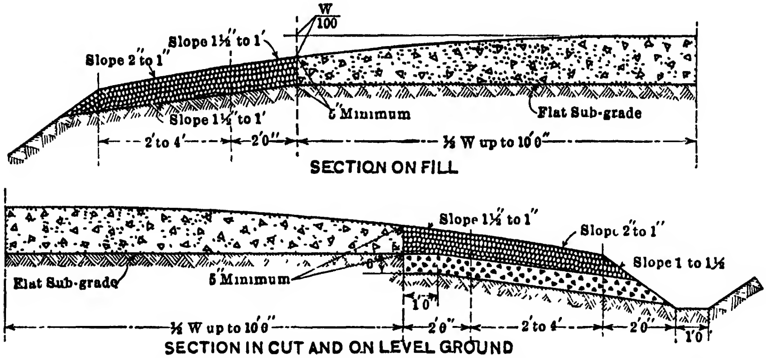


Fig. 38.—Cross-sections recommended by American Concrete Institute

EARTH FOUNDATION

Preparation of Subgrade.—It is believed that in many instances the cracks in concrete road and pavement surfaces are due to unequal settlement of the foundation, and, therefore, it is desirable to take every precaution in preparing the subgrade, to insure but slight and uniform settlement. The effect of long-continued traffic on an earth road is to form a crust of hard-packed earth over the portion of the road most used. On a country road the width of such a crust is about 10 or 12 ft., and on a street 15 to 20 ft. This crust or dense layer of soil often extends to the depth of 2 ft. In shaping the subgrade only the upper portion of this is disturbed. At each edge of the hard portion, the earth roadway is less dense because it has had less traffic. The edge of the concrete road or pavement, therefore, rests on slightly less dense soil than that at the middle and settlement at the edge will be more marked than at the middle. This will be likely to result in longitudinal cracks near the center line of the pavement. No amount of rolling will bring the outer portion of this subgrade to the density of the middle portion if that middle portion has received the puddling action of traffic for years. There-

fore, in the preparation of the subgrade the problem is to bring the middle portion to somewhere near the density of the outer. This can be done by plowing the entire width of the subgrade, bringing it all to a uniform condition, shaping it and then rolling until solid. Such treatment will insure nearly uniform density across the subgrade.

Similarly, when the profile of the road passes from cut to fill, there will be in the vicinity of the transition a section of concrete which is on top of the old undisturbed roadway for a part of its length and on new made cut or fill for the remainder. Here again unequal density exists in the foundation and unequal settlement and transverse cracking is inevitable. The difficulty can be overcome by loosening the entire subgrade, shaping it and then rolling to bring it to uniform density.

As with many other types of hard surfaces the best results will be obtained when the grade-reduction work is completed and the earth surface traveled for a time prior to placing the concrete surface. This will insure that there will be little settlement of the fills after the concrete surface has been constructed and excessive cracking will, therefore, be avoided.

Rolling the Foundation.—In every case the foundation should be thoroughly and repeatedly rolled and special precautions taken to remove any soft places that appear during the rolling.

It is apparent that thorough subsurface and surface drainage are prerequisites of successful concrete road construction. While drainage is important with any type of surface, it is probably more so with concrete than with any other.

PLACING THE CONCRETE

Mixing and Placing.—A well-designed batch mixer is specified for concrete for road or pavement construction, and the type of self-propelled machine with a material hoist for loading and either a boom-and-bucket, or a chute for delivering the concrete is commonly employed. Of these, there are many kinds about equally satisfactory, and the advantage in their use lies in the fact that concrete is deposited directly from the mixer and the aggregates, therefore, have no opportunity to separate as sometimes happens when concrete is conveyed for a distance in carts or barrows. The sand and stone for the concrete are deposited on the subgrade, after it has been rolled, in quantities just suffi-

cient to make the requisite thickness of pavement. The materials are put in at one end of the mixer and discharged at the other, the mixer moving along the subgrade as fast as the material is used up.

The sand and stone for a batch of concrete are carefully measured in special barrows or in bottomless measuring boxes placed in the ordinary barrow.

A recent development is to load the aggregates into a small tram running on 18-in. gage track. The box on the tram is divided into two compartments of the right size for sand and

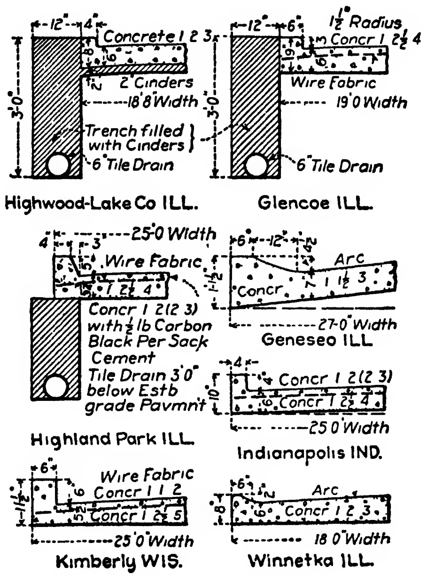


FIG. 39.—Cross-sections for integral curbs on concrete pavements.

stone respectively. The tram is run up to the loading hopper and dumped. The track is in sections which are taken up as fast as necessary and shifted farther back along the stock pile.

Some outfits of recent design have a mixer of sufficient capacity to mix 40 cu. ft. of material at a batch. The aggregates are hauled in 1½-yd. industrial railway cars, each car being loaded with the proper amount of sand and stone for one batch of concrete. The cars are drawn to the mixer and dumped directly into the hopper.

If the width of the pavement does not exceed about 30 ft., the entire width is placed at one operation and is struck off by means of a template which spans the entire width of the roadway. On a

street carrying a car track the section between the track and the curb can be placed at one operation and the form at the track will serve as a guide for the template, while the curb which has been previously constructed will serve as a guide at the gutter. If the pavement is wider than about 30 ft., as would be the case with pavements on streets having no car tracks, transverse forms are

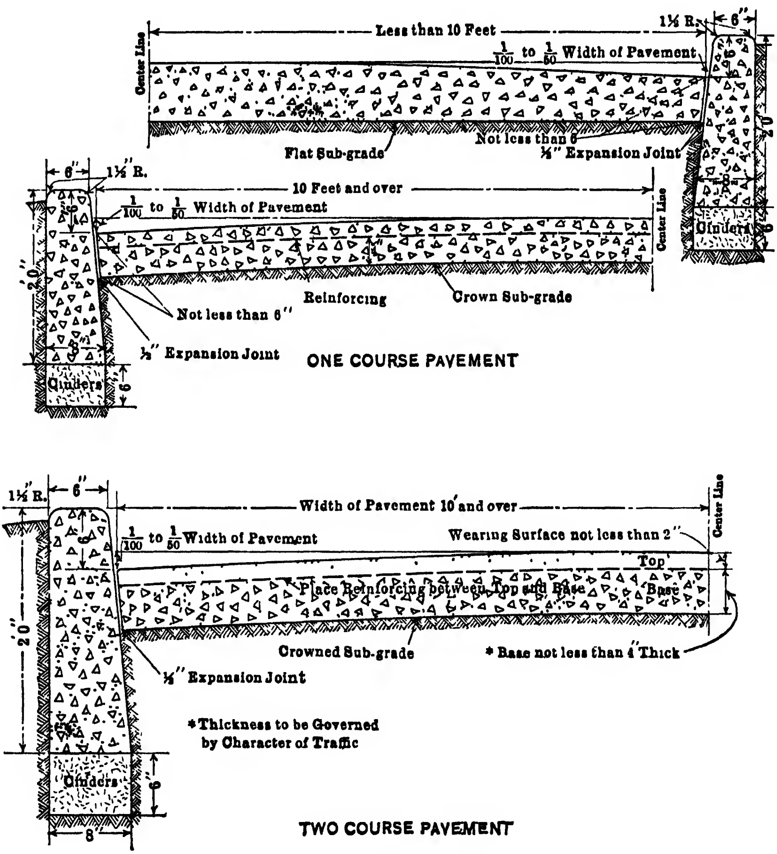


FIG. 40.—Cross-sections for concrete pavements.

usually set and the concrete struck off by means of a straight edge resting on the transverse forms. Longitudinal form boards at the middle of the pavement are avoided since they inevitably form a line of weakness which results in longitudinal cracks. The transverse forms are usually placed so as to form expansion joints. Strike boards spanning streets as wide as 40 ft. have been used

successfully but extreme care is required in their construction if sagging is to be avoided.

In country-road construction side forms are placed at each edge of the pavement and the strike board is drawn along the tops of the side forms. Several types of strike board are shown in Fig. 44.

Extreme care is exercised in placing the concrete to insure a uniform texture of surface. The concrete must not be mixed too wet, or separation of the aggregates will occur when the concrete is deposited. After the surface has been struck off to the desired shape it is finished with a wood float, the laborers working from a bridge which spans the roadway. Excessive floating is undesirable because of the possibility of wearing hollow places in the surface, and the finishing is preferably delayed until the cement begins to set up, which is generally about an hour after the concrete has been mixed. Some engineers prefer to finish the surface as soon as possible after the concrete has been placed.

Curing the Concrete.—Since the surface of the concrete road will be subjected to abrasion it is desirable for the concrete to be as tough as possible. Concrete that dries out is much inferior to concrete that is kept moist and sets properly, and the curing, therefore, consists in protecting the surface from drying and in furnishing plenty of water for the setting. As soon as the cement takes the initial set, the surface is covered with canvas which is sprinkled constantly. Then as soon as the concrete has set sufficiently, it is covered with about 2 in. of clay or loam. Because of its tendency to dry out rapidly, sand is not a good covering unless it is put on to a depth of 3 or 4 in. The covering is kept wet for 2 or 3 days and then kept moist for about 10 days. The first 10 hr. after the concrete surface has been finished is the critical period for it and the durability of the road is largely determined by the care taken during this brief period.

Expansion Joints.—The value of expansion joints in concrete pavements is as yet unestablished, and the trend is toward their elimination. Custom and current practice is to make expansion joints at intervals of 25, 35 or 50 ft. if they are used at all. Some engineers prefer one spacing, others another. If it is assumed that the tensile strength of concrete is 50 lb. per square inch, then theoretically the spacing of the joints should be about 50

ft.; nevertheless many roads have been constructed with this spacing and the concrete slabs have cracked between joints.

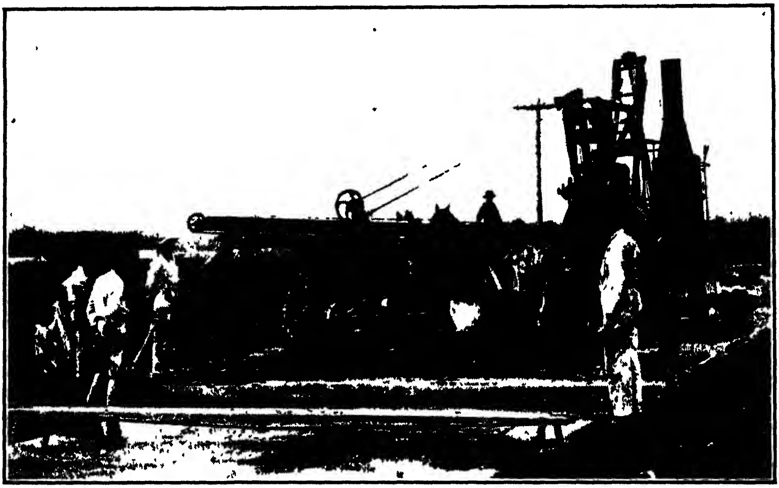


Fig. 41 —Mixing and placing concrete on a rural highway.

There are, however, apparently about as many transverse cracks on pavements having joints spaced 35 ft. apart. The American Concrete Institute recommends that where joints are used they

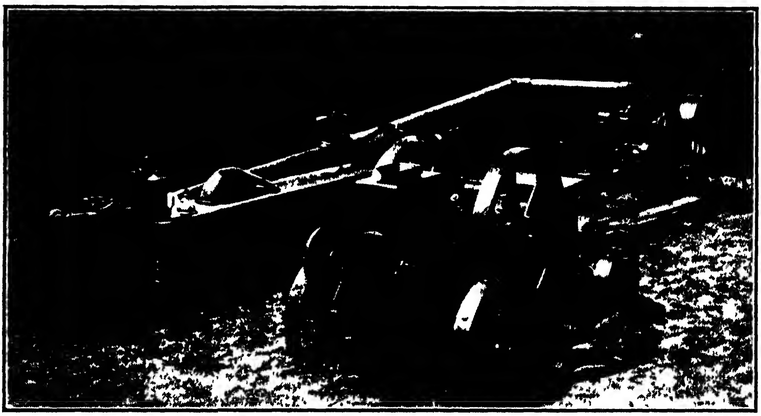


Fig. 42.—A water supply station for concrete road construction.

be spaced at intervals of from 50 to 75 ft. and that the expansion material consist of a layer of felt ⅜ in. thick.

Protection plates have been used extensively at the expansion

joints. These plates are so placed that the edge is flush with the surface of the concrete. They are made of soft steel and the two plates that constitute a joint are separated by a layer of treated felt the thickness of which may be as little as ⅛ in. and is seldom more than ⅜ in. Experience seems to indicate that the metal plate is unnecessary and even a detriment. It does not wear down as fast as does the concrete, the result being a high place at the joint and a low place at each side.

Whatever type of expansion joint is employed, the concrete at the joint ought to be neither higher nor lower than the slab back from the joint. Considerable difficulty has been experienced in finishing the concrete to the same elevation on both sides of the joint, but recently a split-wood float has been devised that insures a good finish at the joint. This float spans the joint and thus brings the concrete on each side of the same elevation.

Reinforced-concrete Pavements.—It is often recommended that when pavements exceed 20 ft. in width, reinforcement of

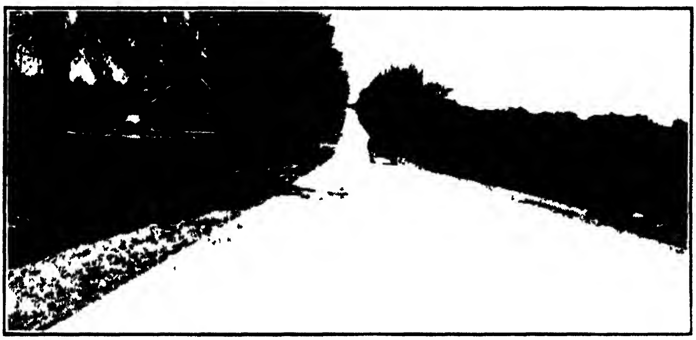


Fig. 43.—Well-built concrete road.

some kind be used for the purpose of preventing sizeable cracks and to distribute the stresses due to temperature and moisture. The amount of such reinforcement recommended by the American Concrete Institute is about 0.049 sq. in. of reinforcement per foot of pavement length and 0.038 sq. in. per foot of pavement width. The reinforcement may be a wire mesh or expanded metal made up to give the desired amount of reinforcement in each direction, or it may consist of square or round rods. The advisability of such reinforcing is still a matter which is based on opinion rather than on definite experimenta-

tion but under average condition the reinforcement should be employed. Where bad foundation is encountered, reinforcement designed especially to care for those conditions is employed.

Characteristic of the Concrete Road.—The well-constructed concrete road has a granular, uniform, easy-riding surface which affords excellent traction for motor vehicles and fair foothold for horses. It is relatively free from dust, but is somewhat trying to the eyes in bright sunshine due to its white color. When built well, it resists abrasion well, except at unprotected cracks or joints, but when a break occurs deterioration is rapid. The cost varies from $1.25 per square yard of surface to $1.65 for a thickness of 8 in. at the crown line and 6 in. at the edge. As to the durability or ultimate life, experience does not yet permit a definite statement to be made but every indication is that it is a durable type of pavement if properly built and properly maintained.

Maintenance.—The defects that appear in the concrete pavement under traffic are (*a*) longitudinal and transverse cracks, (*b*) pits in the surface where pebbles or stones have disintegrated and been picked out, (*c*) abrasion or breaking down at the expansion joints, and (*d*) gradual wearing of the surface. The method of maintenance is the same for all of these defects. A bituminous material, usually a soft grade of tar, but occasionally a similar grade of asphalt, is poured into the cracks and into the pits in the surface and into the expansion joints and is then covered with coarse sand or chips of hard stone. This method of maintenance if properly carried out will probably serve indefinitely and the only deterioration will be the natural wearing away of the surface under traffic. Many attempts have been made to minimize this effect by covering the entire surface with a layer of some kind of bituminous material. These attempts have been made with varying success, but appear to give promise that a material will eventually be manufactured that will adhere to the surface and will thus form a cushion protecting the concrete from abrasion. As a matter of fact, such a surface is being used extensively on the California State highways and is proving successful. The climatic conditions are perhaps advantageous to this material in California, but it seems that a similar treatment will be worked out for roads in other localities. The best results so far seem to have been ob-

tained with a light grade of tar and with a light grade of asphaltic oil. Such a surface apparently will be satisfactory for 2 or 3 years when it will need to be replaced. This, however, does not constitute an expensive maintenance charge, and if, as believed, it prolongs indefinitely the life of the pavement, it will be justified.

Concrete Road with Bituminous Top.—The State of California has constructed many miles of concrete roads with a thin wearing surface of asphalt and stone chips. The concrete road proper is 4 in. thick and the mixture is 1-2½-5. This method of construction has attracted wide attention and the following is a brief description of the methods employed and the material used.

"In this method of construction,[1] the base is the same as if the 1½- to 2-in. asphaltic concrete covering were to be applied, but instead a thin coating of asphaltic oil of special quality is put on to the concrete by spraying machines at the rate of about ½ gal. to the square yard. Clean stone screening or coarse sand are then added in sufficient quantity to absorb the oil. The process requires much care in the selection of the materials used and in their manipulation but the result is a bituminized coating about ⅜ in. thick. The cost of such surface work ranges from 5 to 10 cts. per square yard of pavement, depending on the cost of materials and local conditions. This means that more than 90 per cent. of the cost of the work on the road goes into grading, culvert work and the concrete base, all of which may be considered as practically permanent, and the remainder into the thin wearing surface.

"Such a wearing surface should last from 2 to 4 years before it requires renewal, which renewal should cost considerably less than the original application. The thin surface is best adapted to rubber-tired vehicles, but it wears well under a considerable volume of mixed traffic consisting of both rubber- and iron-tired vehicles. The thin road surface can be recommended for a road carrying as many as from 500 to 600 vehicles a day, provided a considerable portion of the vehicles are rubber-tired."

The following is the specification for the asphaltic oil used on the California work.

Specification for Road Oil.—(*a*) The oil shall be a natural oil with an asphaltic base, treated to remove water or sediment, or the residuum of such an oil from which the volatile material

[1] A. B. Fletcher, State Engineer of California, in "California Highways."

has been removed by distillation, and shall be satisfactory to the engineer. It must not have been injured by overheating, and it must not be obtained by adding solid asphalt to lighter oils or distillates.

(*b*) In determining the quantity of oil delivered, the correction for expansion by heat shall be as follows: From the measured volume of oil received at any temperature above sixty (60) degrees F. an amount equivalent to four-tenths (0.4) of one (1) per cent. for every ten (10) degrees above sixty (60) degrees F. shall be subtracted as the correction for expansion by heat. For the purpose of measuring oil, a temperature of sixty (60) degrees F. shall be deemed a normal temperature.

(*c*) Deduction will be made for water and sediment in exact proportion to the percentage of water and sediment found therein, and the oil shall not contain over two (2) per cent. of such water and sediment.

(*d*) After being freed from water and sediment, the oil shall contain not less than ninety (90) per cent. of asphalt, having at a temperature of seventy-seven (77) degrees F. a penetration of eighty (80) degrees District of Columbia standard. The percentage of asphalt shall be determined by heating twenty-five (25) grams of said oil or residuum in an evaporating oven at a temperature of four hundred (400) degrees F. until it has reached the proper consistency, when the weight of the residuum shall be determined and the per cent. calculated.

(*e*) The oil shall show an adhesive strength of not less than three hundred (300) seconds when tested at a temperature of seventy-seven (77) degrees F. by the Oshorne adhesive test apparatus at the laboratory of the California Highway Commission. The oil shall show a specific viscosity of not more than one hundred (100) when tested with the Engler viscosimeter at a temperature of two hundred and twelve (212) degrees F.

(*f*) Residuum shall not contain in excess of two-tenths (0.2) of one (1) per cent. of organic matter insoluble in carbon tetrachloride at ordinary temperature, after the removal of the percentage of water and sediment.

MACHINERY USED FOR CONCRETE ROAD WORK

Mixers.—Any batch mixer of good design may be used for concrete road and pavement construction, but the self-propelled

type with some sort of boom or chute for distributing the concrete has come into wide use. It is best to spread and finish the concrete immediately behind the machine, which makes this type of mixer particularly desirable. The two-sack batch size is quite widely used. The later models have the batch meter for

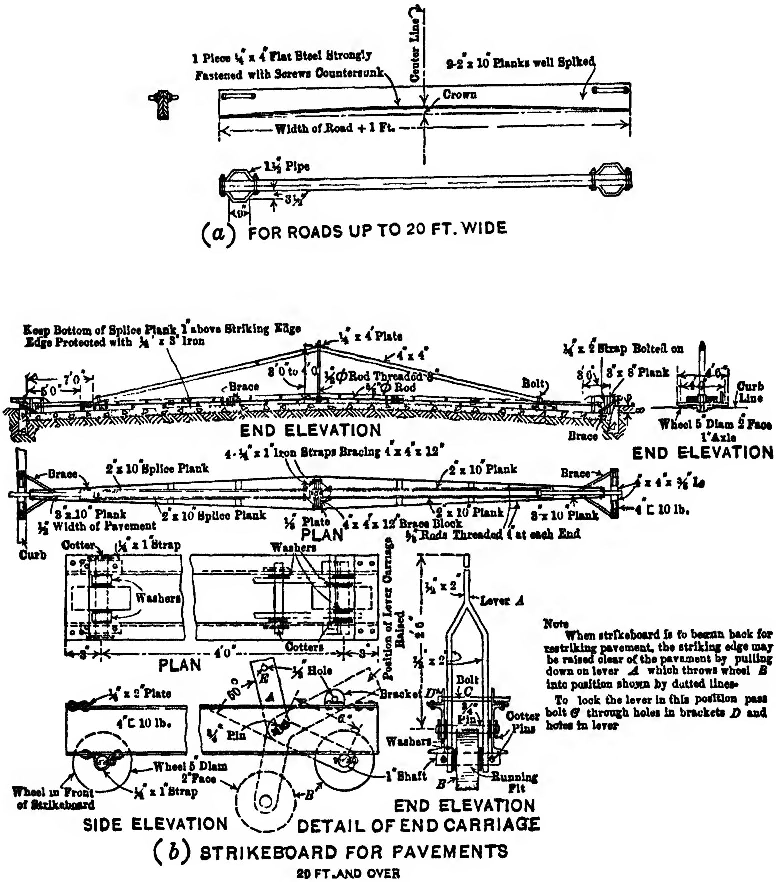


Fig. 44.—Strike boards for concrete roads and pavements.

indicating when the batch has been mixed long enough, automatic water tanks, and loading skips.

The delivery may be by means of a bucket traveling on a swinging boom, by means of a rotating cylindrical chute, or by means of a straight chute. Probably there is no great difference between the first two methods of depositing the concrete so far

as flexibility is concerned, but the third has a somewhat limited radius of delivery due to the fact that a relatively short spout must be used to secure enough slope.

The mixer travels along the road under its own power, being equipped with a special clutch which can be thrown in with a lever whenever it is desired to move the machine.

Rollers.—The three-wheeled roller weighing about 8 tons or the tandem type of roller of about the same weight is used for compacting the foundation.

The single roller drawn by teams is also used, but it is not to be recommended.

Finishing Bridge.—The essential of the finishing bridge is that it be reasonably light so as to be easily moved and that it be strong enough to support two men. It must be supported low enough to permit the men to reach the surface readily with the floats.

Strike Board.—The strike board or template used to strike off the surface is a 2-in. plank about a foot wide at the ends and having one edge cut to fit the crown of the road. The striking edge is faced with a metal strip. At the ends metal handles are provided for convenience in operation and if the length exceeds about 10 ft. a rod is attached at the middle so that a laborer can assist in pulling the board along.

In some instances a strike board is made double, and that is with two 1¼-in. planks about 6 or 8 in. apart. This form of template does not have any advantages over the single-plank to compensate for the greater weight.

For streets wider than 16 ft., the strike board must be carefully trussed to prevent its springing while in use. Not infrequently the longer templates are arranged with rollers at the ends which follow the top of the side form thus carrying the weight of the template and facilitating its operation.

Finishing Floats.—The concrete road or pavement is almost universally finished with a wooden float. It may be the ordinary float about 6 in. wide and 12 to 14 in. long with the handle affixed to the top, or it may be the larger float which is about 12 in. by 16 in. and has a handle about 4 ft. long.

Several attempts have been made to construct mechanical floats and doubtless these will eventually be successful. The general plan is to arrange a series of small wooden floats on a

chain or cable and to cause them to be dragged across the surface.

For finishing at the expansion joint the split float is used, the two parts of the board being separated by a slot about 2 in. wide. The slot spans the joint filler and insures that both sides will be finished to the same elevation.

Joint Setting Devices.—If metal protection plates are used at the expansion joints, special devices are sometimes employed for setting them. The device consists of a bar of tee section bent to conform to the cross-section of the road surface. The pair of protection plates with the felt filler between is clamped to the setting bar, the ends of which rest on the side forms. After the joint is in place and the concrete has been spread and has partially set, the teebar is removed and the surface next the joint smoothed to remove the marks of the clamps.

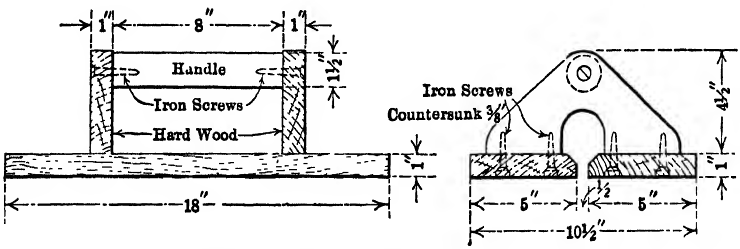


Fig. 45.—Split float for finishing along expansion joints.

Water Supply Equipment.—Where concrete roads are constructed in the country a special water-supply system must be installed. This outfit consists of a plunger pump having a capacity of about 100 gal. per minute and the necessary engine for driving it. Usually a gasoline engine is used for the purpose. The supply pipe, which is never smaller than 1¼ in. and is usually 1½ or 2 in. is laid along the road. The mixer is connected by means of a hose of sufficient length to permit the machine to move along the road for some distance before changing the hose to a new connection on the pipe. Hose connections are also provided for convenience in sprinkling the finished concrete.

Oil Distributors.—For bituminous-coated concrete road the pressure distributor described in connection with bituminous carpets is used.

TABLE 12.—COST OF CONCRETE ROADS

Milwaukee County, Wisconsin

Average cost per square yard for an average thickness of 7 in.	
Cost of sand and stone	$0 27
Unloading aggregates to hauling vehicles . . .	0.05
Hauling materials average of 2½ miles.	0.27
Mixing and placing.	0.20
Metal protection plates for expansion joints . . .	0.03
Furnishing water.	0 02
Cement.	0.45

Allowance for contractor's profit and for liability insurance is in addition to the above.

TABLE 13.—ILLINOIS STATE AID CONCRETE ROADS, 1914

(Actual Contract Prices)

Road No	Width	Costs per mile			Length, feet	Cost of concrete per square yard
		Grading	Concrete	Macadam		
I.	10 ft. concrete; 4 ft. mac. . . .	1,965	8,400	1,780	7,200	1 43
II.	10 ft. concrete	1,430	6,300		6,009	1 07
III.	10 ft. concrete; 4 ft. mac. . .	1,330	7,840	2,380	9,000	1 34
IV.	18 ft. concrete	6,040	11,600		24,000	1 10

EXAMPLES OF GOOD PRACTICE

CONNECTICUT STATE HIGHWAY DEPARTMENT[1]

Among the features to which special importance is attached are the following: Thorough rolling of the subgrade; adequate provision for drainage; a specified minimum time for the mixing of each batch of concrete; careful grading of the concrete aggregates; thorough washing of sand; curing of the finished road; accurate measurement of concrete materials in boxes instead of rough wheelbarrow measurement; use of steel reinforcement; and the placing of tar-paper expansion joints at 30-ft. intervals.

The Milford turnpike is a single-course reinforced-concrete road, 18 ft. wide, with 5-ft. macadam shoulders. It is 8 in. thick at the center and 6 in. at the side and is reinforced with the American Steel & Wire Co.'s No. 29 wire mesh. The new pave-

[1] *Engineering Record*, Apr. 17, 1915.

ment rests upon an old macadam foundation which had begun to show signs of wear.

Provision for Drainage

Before the construction season opened a thorough examination of the old macadam road was made to detect poorly drained sections. After a heavy rain, when the frost was leaving the ground, these bad spots were located with stakes, and when work began they were replaced by a 15-in. subbase of washed gravel, varying in size from 1/4 to 1 1/2 in. This gravel subbase was

Fig. 46.—Concrete road and concrete guard rail.

drained into the side ditches at suitable intervals. In Connecticut the experience has been that a gravel foundation of this type is more satisfactory, under concrete, than a Telford base, for it is less subject to the influence of frost. The 15-in. gravel base can be put in at the same price as an 8-in. Telford foundation.

In preparing the new subbase, which is flat, a definite policy of cutting down the old macadam crown was adopted. If the full thickness of the old 7-in. surface at the center line of the road had been used to support the new pavement, the fill necessary to bring the grade horizontal at the shoulders would have been excessive, and even if rolled thoroughly might have settled and caused cracking in the finished concrete. On the other hand,

if too deep a cut was made at the crown the full supporting value of the old road surface would not have been realized. On the Milford turnpike the depth of cut at the crown was fixed at 3½ in., giving a fill of 2 in. at the side, using the material which has been removed from the center of the roadway.

Where it was necessary to put in the gravel subbase particular attention was given to making the foundation compact, and the material was watered and rolled to a solid bearing with a 15-ton steam roller. On side-hill work a drain, 2 ft. wide and 40-in. deep, filled with crushed stone, was constructed on the uphill side to intercept the water before reaching the roadbed, and 6-in. tile pipe with open joints was used for carrying the water.

Concrete Aggregates

The coarse aggregate for the concrete was a local trap rock with high abrasive qualities. Coarse sand was used and the washing

Fig. 47.—Cracks in a concrete road filled with tar to prevent excessive wear.

of the fine aggregate was made compulsory. For the sand it was specified that not more than 15 per cent. should pass a 50-mesh sieve and that the tensile strength should be equal to that of briquettes made with standard Ottawa sand. The contractor was required to deliver the stone on the work in three sizes—

½, ¾ and 1¼ in. No mixing of these sizes was permitted before delivery. When the stone reached the work tests were made to determine the proportions for the densest mixture and the one which could be worked to best advantage, special attention being paid to these points. The value of washing the sand was proved conclusively by an experience on a nearby contract, where this requirement was not made, and where the work was of an inferior quality as a result. All of the cement was required to pass the test of the American Society for Testing Materials.

Placing Concrete

The mixture used was 1 part Portland cement, 2 parts sand and 4 parts crushed trap rock. These materials were mixed and delivered to place by a bucket and boom. A rigid rule was enforced requiring the contractor to turn each batch in the mixer at least 1½ min. The good quality of concrete produced is attributed in part to this feature of the construction routine. The progress in concreting was 300 ft. of 18-ft. roadway per day of 9 hr., amounting to about 120 cu. yd. of concrete.

Boom Mixer Used

It was noted that the boom bucket which received the mixed concrete was not water-tight and that after the plant had been in place for awhile the drippings of cement and sand grout formed a small mound under the loading point. If this mound of material had been allowed to remain in place, it would have produced a soft spot in the finished pavement, for since it contained no coarse aggregate it would have had slight resistance to the abrasion of passing traffic. These mounds of grout, therefore, were always removed wherever the position of the mixer was changed and were replaced with concrete containing the standard proportions of coarse stone. This is one of the small details of the work which are believed to have been responsible for good results.

The wire-mesh reinforcement was delivered in rolls of 60-in. width and was laid transversely. At places where bad spots had existed in the old subbase, the reinforcement was placed near the bottom of the concrete slab to take up any stress due to settlement. Elsewhere the steel was placed 2 in. below the top surface, to counteract any heaving due to frost action.

Expansion Joint

The pavement was laid in 30-ft. sections with an expansion joint of three thicknesses of tar paper between sections, when the weather was cool, and two thicknesses during the warmest period. For the placing of these joints a 1½-in. pine board was set up across the roadway and the tar paper tied to it with string, allowing about ½ in. of the paper to project above the finished

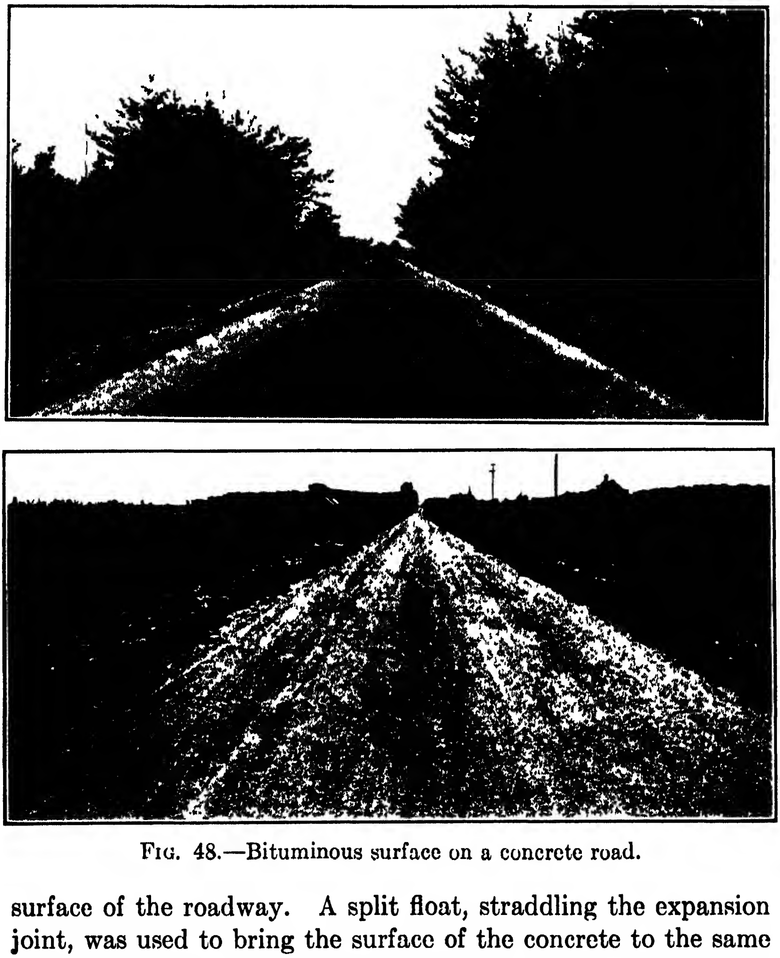


Fig. 48.—Bituminous surface on a concrete road.

surface of the roadway. A split float, straddling the expansion joint, was used to bring the surface of the concrete to the same elevation at each side, thus avoiding any bumps in the finished work which the wheels of passing vehicles would chip off. When the concrete had reached its final set, the projecting tar paper

was cut off a quarter of an inch above the surface of the road with a shovel, and when traffic was allowed on the road the projecting edges of the paper were broomed over, forming a protection for the edges of the concrete. Joints of this type have given about a year's service and then are treated with a mixture of tar and sand, a maintenance operation costing about $15 per mile. As a result of the experience the engineers believe that the tar-paper joint is better than steel, for with a steel joint it is difficult to bring the top surface of the concrete to the same curve as the steel plate. The steel joint also adds about 4 cts. per square yard to the cost of the pavement.

Parallel to the center line of the roadway at either side are placed 6 by 6-in. wooden stringers held in position by 1-in. iron pins. These stringers serve as the side forms for the concrete work.

The pavement is floated from a plank bridge, and is scored transversely with rattan brooms to prevent slipperiness. The screeds used are 2½-in. plank with iron shoes, resting upon the 6 by 6-in. wooden stringers.

A Few Construction Details

In forming the joints it is important not to work the concrete so that cement mortar alone is present at the end of the section. If this happens the joint will be weak and will chip off quickly under traffic. It is essential to have a certain quantity of stone at the end of each section to resist abrasion.

Another detail of construction which experience has shown is well worth following is the accurate measurement of concrete aggregates prior to their delivery to the mixer. The ordinary wheelbarrows were not allowed for this purpose but instead, the wheelbarrows were fitted up with calibrated boxes. With these devices available for accurate measurements, there was no guesswork in the proportioning of the concrete.

The final operation in the construction of the concrete road consisted in covering it with 2 in. of earth, which was kept moist for a period of 8 days. Water was pumped from the river to a standpipe at the middle of the job through a 2-in. pipe line laid by the contractor. No section of the road was opened to traffic until 2 weeks after the concrete had been placed.

CONCLUSIONS OF THE SECOND NATIONAL CONFERENCE ON CONCRETE ROAD BUILDING, FEBRUARY, 1916

Specifications

Since no specifications were considered by the Conference, ths Standard Specifications for Pavements and Roadways of the American Concrete Institute are recommended.

Drainage

The drainage of the roadbed is of vital importance. If the subgrade is not well drained there is danger of unequal settlement or frost action, which will cause cracks. The method of drainage to be used will depend on local conditions. For streets, as well as roads, tile drains may be used which should be laid on each side of the roadway, or on one side only, with cross-drains leading thereto at a suitable depth, depending on the width of the pavement. Drainage trenches, if placed under the subgrade, should be completed before final rolling.

Grading

When roadways are constructed over fills, extreme care should be observed to insure the use of proper materials in layers of such thickness that they may be thoroughly compacted so that when the fill is completed there will be a minimum of settlement. In general, fills shall be made in thin layers, the depth depending on the character of material to be used in making the fill. The fill should be allowed to stand for as long a time as possible, giving it an opportunity to settle thoroughly before the pavement is placed thereon. Deep fills should be allowed to settle through one winter wherever such procedure is possible. Puddling will be found advantageous in compacting deep fills. Wetting and rolling shall be performed when making a fill in order to secure thorough compactness. Fills should never be made with frozen materials nor with lumps greater than 6 in. in their greatest dimension.

Subgrade

The fundamental requirement of the subgrade is that it should be of uniform density so that it will not settle unevenly and cause cracks in the surface of the pavement. No part of the work is more worthy of intelligent care and painstaking labor than the preparation of the subgrade. The slight additional cost necessary to insure good results is abundantly justifiable. When the pavement is constructed on virgin soil, care should be taken to remove all soft spots so as to insure a

uniform density; and if constructed on an old roadbed, even greater care must be taken to secure uniform density, as the subgrade is likely to be more compact in the center than at the sides. An old roadbed should be scarified, reshaped and rolled. The subgrade adjacent to curbs should be hand-tamped.

Materials

Portland Cement.—Portland cement shall meet the requirements of the standard specifications for Portland cement of the American Society for Testing Materials and tests should be made in accordance with the methods of tests outlined by the American Society of Civil Engineers.

Aggregates.—The selection of proper aggregates for concrete road construction is of utmost importance. Clean, hard, well-graded materials are absolutely essential to success. For this reason samples of the materials proposed for use should be submitted to the engineer for approval before orders are placed. These samples should be carefully inspected; and if possible, laboratory tests made to determine their suitability. If laboratory tests on shipments cannot be made, field tests can be used to furnish a general indication of quality.

The different aggregates should be kept clean and separate.

Aggregates to be used in the wearing course of two-course pavements should never be placed on the subgrade but on planks or some other means provided to keep them free from dirt. When aggregates are placed directly on the subgrade care should be used by the shovelers to avoid getting clay or earth shoveled from the subgrade into the mix. Aggregates should not only be clean when they are delivered on the job, but clean when placed in the mixer.

Water.—Water supply is a most important factor and is frequently overlooked by the engineer and contractor. A large supply of water is necessary for (*a*) sprinkling the subgrade; (*b*) mixing the concrete; and (*c*) keeping the concrete moist during early stages of hardening. For this latter purpose 25 or 30 gal. per square yard of pavement will be required during the summer months. Insufficient sprinkling is detrimental to the wearing qualities of the pavement.

Reinforcement.—The use of reinforcement in concrete pavements is increasing.

A coating of light rust will not be detrimental to satisfactory results but care should be exercised that no excessive rust, paint or other coatings are present to interfere with proper bond. Care should also be exercised to see that the reinforcement is so stored, prior to use, that it is not covered with mud or clay when placed in the pavement. Reinforcement left on a job when contract is not completed at the end of the season should be collected and stored so that it is protected from the

elements. Occasional tensile and bending tests should be made to see that the requirements of the specifications are fulfilled.

Joint Filler.—Joint filler should preferably be of a single thickness. Transverse joint filler should be cut to the crown of the pavement by the manufacturer when metal plates are used. A type of joint filler which will iron out readily under traffic is preferable for use in unprotected joints. A joint filler which will not bend easily when concrete is deposited against it is to be preferred.

Joint-protection Plates.—Metal joint-protection plates should be properly bundled and wired by the manufacturer so that they will arrive on the work in good condition, free from warp. Protection plates up to 20 ft. shall be shipped in single lengths. The exact length should be provided so that the contractor will not find it necessary to cut plates. In cutting plates for length, spacing between eccentrics on the installation bar should be considered to avoid interference with anchorage lugs on plates. Particular care should be used by the manufacturer in crowning the installing bar, to avoid the necessity of duplication of work by the contractor.

Forms

Metal forms of sufficient strength to withstand the necessary hard usage are preferred. When wooden forms are used they should be of at least 2-in. stock and capped with a 2-in. angle iron, so constructed that adjacent sections can be lapped. Forms should have a width not less than the thickness of the pavement at the sides. Particular care should be exercised to see that the top edge of forms are clean so as to avoid unevenness in the finished pavement. If forms are warped or stakes not properly placed, a poor alignment of the edge of the concrete slab will result.

Pavement Section

Thickness.—The thickness of a concrete road or pavement is controlled by many factors, each of which should be given consideration. In view of the increasing use of the heavy motor truck and bus, it seems unwise to build pavements with a thickness of less than 6 in. at any point. In general, pavements shall be thicker at the center than at the sides. Alleys with an inverted crown and narrow one-slope roads should have uniform thickness. Wherever the thickness can be increased without excessive cost, to secure a flat or nearly flat subgrade, such increase is advisable.

Width.—The desirable width for single-track road is 10 ft. The desirable width of double-track roads is 18 ft. The total width of the roadway should not be less than 20 ft. for single-track roads and not less than 26 ft. for double-track roads.

Crown.—The crown of roads and pavements should be not less than one one-hundredth nor more than one-fiftieth of the total width. Except in unusual cases, one one-hundredth will be sufficient for country roads and one-fiftieth will be considered satisfactory for alley pavements. For city streets an average crown of one seventy-fifth will generally be found sufficient and should not be reduced, except on grades.

Joints

Transverse Joints.—Joints should be placed across the pavement perpendicular to the center line about 50 ft. apart.

There seems to be a tendency to widen the distance between joints.

Joints should extend entirely through the pavement as well as through the curb if integral curbs are used. Joints should be constructed perpendicular to the surface of the pavement to avoid the possibility of one slab rising above the other.

Longitudinal Joints.—Longitudinal joint filler should be staked or otherwise securely held against the curb. Joint material should also be placed around manholes, catch-basins, etc.

Protected Joints.—The tendency of present practice is toward the omission of metal protection plates for joints. It is possible that the value of metal protection plates is dependable somewhat on the character of aggregate used, and it is considered that they are more essential in street pavements than in country highways.

Plates.—Plates for protected joints should be wired together with the joint filler in place and securely held in the installing bars. When short sections of joint filler are used they should likewise be wired together. Supports for the joint should be used when the pavement is of such width that the installing bar deflects. On wide streets every joint should be checked as to crown with sighting T's. When necessary to have joint plates in two sections, the contractor should arrange with the manufacturer to have holes drilled in the abutting ends of the plates so that the plates may be securely wired or strapped together. As the joint plates usually do not fit tight to the installing bar, a ¼-in. shim is placed under each end of the installing bar, to insure that the plates are not covered by the concrete.

Mixing and Placing Concrete

Measuring.—The method of measuring materials for the concrete, including water, should be one which will insure accurate proportions of each of the ingredients at all times. It is recommended that a sack of Portland cement, containing 94 lb. net, be considered the equivalent to 1 cu. ft.

Proportioning.—The proportions should not exceed 5 parts of fine and coarse aggregate measured separately to 1 part of Portland cement, and the fine aggregate should not exceed 40 per cent. of the mixture of fine and coarse aggregates.

Aggregates.—Bank-run material should not be used. Proportioning based on sieve analysis or by relative density tests is not practicable for concrete roads, except where laboratory direction is available; but where proper facilities are available the above proportions should be varied as the tests warrant.

Mixing.—The ingredients should be mixed in a batch mixer. The mixing should be continued for at least 1 min., after all the materials are in the mixer and before any of the concrete is discharged. The speed of the mixer should not exceed 16 revolutions per minute; however, the time and not the number of revolutions should be the gage of proper mixing.

Consistency.—The practice is to mix concrete entirely too wet. The consistency should be such as not to require tamping, but not so wet as to cause the separation of the mortar from the aggregate in handling and placing. The strength and wearing qualities of the concrete are vitally lessened by an excess of water in mixing.

Placing.—If the subgrade has been disturbed by teaming or other causes, it should be brought to its former surface, and thoroughly saturated with water. The concrete should be deposited rapidly to the required depth and width. The section should be completed to a transverse joint, without the use of intermediate forms or bulkheads, or a transverse joint may be placed at the point of stopping the work. In case the mixer breaks down the concrete should be mixed by hand to complete the section. Where reinforcement is used it should be embedded in the concrete before the concrete has begun to set; the concrete above the reinforcement should be placed within 20 min. after the placing of the concrete below.

In two-course pavements the top should be placed within 20 min. after the placing of the bottom.

Finishing.—The surface of the concrete should be struck off by means of a template moved with a combined longitudinal and transverse motion. The excess material accumulated in front of the template should be uniformly distributed over the surface of the pavement except near the transverse joint, where the excess material should be removed.

The concrete adjoining the transverse joint should be dense and any depressions in the surface should be filled with concrete of the same composition as the body of the work. After being brought to the established grade with a template, the concrete should be finished, from a suitable bridge, with a wood float to true surface. A metal float should not be used.

Brooming of the surface is not necessary and grooves are objectionable even on grades.

Retempering

Retempering of mortar or concrete which has partially hardened, that is, mixing with additional materials or water, is strongly condemned and should not be permitted.

Protection and Curing

Even the best concrete may be seriously damaged by too rapid drying out, early exposure to low temperature, or by being opened to traffic at too early a period. Hot sun and drying winds are most liable to dry out the concrete too rapidly, thus causing shrinkage cracks or causing a surface which will not wear well under traffic. The use of a canvas covering will be found effective in overcoming this condition.

Sprinkling should also be employed as soon as the concrete is hard enough to prevent the surface being pitted. An earth covering or protection by ponding should be employed after the first day. Under most favorable conditions such protection should be given the pavement for at least 2 weeks. Water should be added during this period to keep the concrete wet.

In cool weather it is often advisable to omit the earth covering, thus allowing the concrete to harden more rapidly. Sprinkling should not be omitted during the day in case the surface shows a tendency to dry out. When there is danger of frost, sprinkling should be omitted and a covering of canvas or straw and canvas used.

Placing concrete in roads and pavements in temperatures at or near freezing is not advisable, and if in special cases, such work is unavoidable, the water and aggregate should be heated and precautions taken to protect the concrete from freezing for at least 10 days. Chemicals to lower the freezing temperature of the mixture should not be used.

Concrete should not be deposited on a frozen subgrade.

Opening to Traffic

Under most favorable conditions a concrete pavement should not be opened to traffic in less than 2 weeks and when conditions permit this interval should be at least 4 weeks.

One-course Pavement

Where the materials most readily available are such as to give good construction in one-course pavement, this convention recommends that the one-course be used.

Integral Curb

The integral curb for concrete street pavements is recommended in preference to straight curb or combined curb and gutter. Such construction eliminates the longitudinal joint along curb, maintains a permanent grade and alignment. Precaution should be taken to insure that the curb is thoroughly bonded to the pavement proper. The integral curb can be used on wide as well as narrow streets.

CHAPTER X

VITRIFIED BRICK ROADS AND PAVEMENTS

The brick pavement is one of the older and more widely used types of pavement developed in the United States. The first brick pavements were built with soft brick and under unsuitable methods of construction and hence were neither smooth nor durable, but both the process of manufacturing the brick and the methods of constructing the pavements have been steadily improved until the brick pavement has become one of the most widely used of all the types. At present, nearly one-half of the paved streets in the United States are of brick.

While it is assumed that the reader has already become familiar with the process of manufacture of paving brick, attention will be called to a few physical characteristics of brick that are of special significance in the paving industry.

KINDS OF BRICK

Repressed Vitrified Brick.—The repressed brick is first moulded slightly thicker than the finished brick is to be, and without spacing lugs. It is then repressed in a mould that puts raised letters or lugs on one face of the brick. The letters or lugs serve to separate uniformly the brick in the pavement so that the filler will flow freely into the joint between courses. If the lettering is too elaborate, it retards the flow of filler somewhat, and a simple design or merely raised lugs are preferred to the more pretentious lettering.

It is generally recognized that repressing has a tendency to weaken the structure of the brick, especially with some kinds of clay. Since practically all paving brick are manufactured by the stiff-mud process, incipient laminations are inevitable, and these may be made more pronounced by the repressing process. In this process the corners of the dies in which the brick are pressed have a small fillet which produces a slightly rounded edge on the brick, a fact that will be noted again. A type of repressed brick is shown in Fig. 49, *e*.

Non-repressed Brick.—In order to eliminate any possible objectionable effect of repressing and to cheapen the process of manufacture several types of brick are now made by processes which avoid repressing. The lugs for spacing the brick in the pavement are secured by various means, and the differences in the processes are chiefly differences in the method of securing the lugs.

Wire-cut Lugs.—In the Dunn process the column of clay is cut the long way of the brick, *i.e.*, the brick are "side cut," and the cutting wire is guided so that it cuts lugs on the brick as shown by Fig. 49, *c*. The vertical faces of the brick are, therefore, the cut faces, and being rough, afford a good surface for the filler to adhere to. It will also be noted that the edges of the

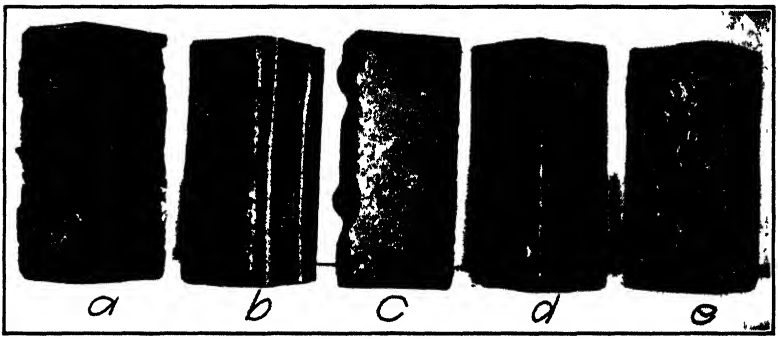


FIG 49.—Types of vitrified paving brick. (*a*) Vertical fibre. (*b* and *d*) Non-repressed. (*e*) Repressed. (*c*) Non-repressed wire cut lug.

brick which form the upper edge of the transverse joint between the rows are square instead of rounded as in the case of the repressed brick.

Vertical Fiber Brick.—The term "vertical fiber brick" is a trade designation for paving brick that are manufactured in such a way that the laminations, if any exist, will be perpendicular to the surface when the brick is laid in the pavement. This type of brick is wire cut, but instead of the wire-cut face being vertical in the pavement, it is the top or wearing face of the brick. To secure lugs, ridges or beads are moulded on one edge of the brick. These beads are vertical when the brick is laid, and extend entirely across the brick. This type of brick also has a square edge at the joint between rows in the pavement (see Fig. 49, *a*).

Another type of non-repressed brick is shown in Fig. 49, *b*. This brick is moulded with two beads outstanding on one face which are subsequently flattened for the middle half of the length of the brick. This leaves four short sections of the bead outstanding to serve as lugs and these are in a horizontal position when the brick has been laid. This type of brick also has rounded edges along the joint between rows.

Still another type of non-repressed brick is shown in Fig. 49*d*. The spacing lugs consist of four raised knobs about ½ in. in diameter. These are moulded on the brick as the clay comes through the dies by a special device attached to the die.

PHYSICAL CHARACTERISTICS OF BRICK

Wearing Qualities.—The wearing properties of brick are determined by the rattler test described in Chapter V. The limits placed on the loss during the rattler test will vary with the class of service demanded. The uniformity of the brick will be shown by the loss of individual brick, and it is, therefore, advisable in many instances to specify both the average loss of the batch of ten bricks and the maximum permissible loss for individual brick. The following table will indicate in a general way the limits that should be put on these two amounts:

Limits for Rattler Loss of Paving Brick

	Average loss	Max. loss for any brick
For brick for heavy traffic	20	24
For brick for medium traffic	22	26
For brick for light traffic	25	28

The quality of brick that should be used in any case is a matter that must be determined for each piece of pavement after a careful analysis of the traffic conditions as explained in Chapter XIX.

Effect of Absorption.—The absorption test indicates the density and in a measure the degree of vitrification of the brick. These facts are also shown by the rattler test, and the absorption test is rarely specified for paving brick. When both the average and maximum loss during the rattler test are specified, it is superfluous to also include the absorption test.

Cross-breaking Test.—The cross-breaking test is rarely specified for paving brick except when brick other than standard

blocks are used. As a matter of experience, brick rarely fail by cross-breaking or crushing.

Size of Brick.—The size of brick commonly used for paving is called the paving block. The length lies between 8 and 9 in.;

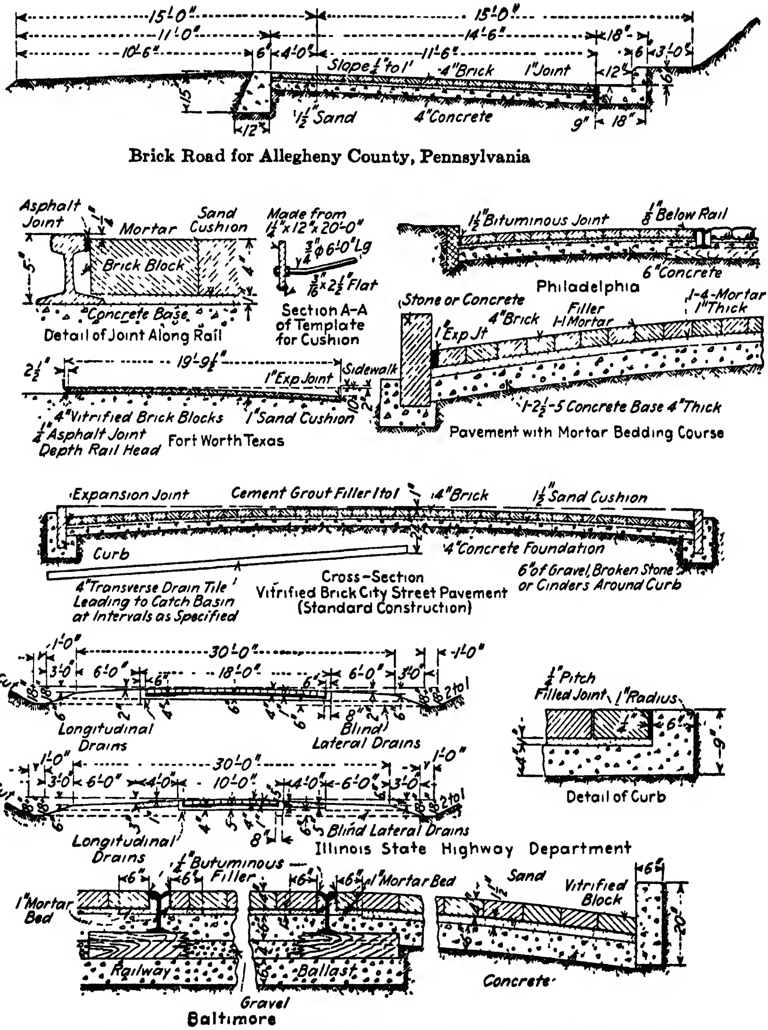


FIG. 50.—Cross-sections for brick roads and pavements.

the width between 3 and 3¾ in.; and the depth between 3¾ and 4¼ in. The block size may be taken as the standard brick for use in all ordinary cases. For light traffic or special conditions

of light service, a brick may be used that will give a somewhat thinner surface. These special brick are usually about the same width and length as the paving block, but the depth is sometimes as little as 2½ in., and 3 in. and 3½ in. are coming into use for the thinner pavements intended for medium traffic.

Regularity of Shape.—The paving block must be sufficiently regular in shape to lie evenly in the pavement and form a smooth surface. For that reason, the brick must be reasonably straight and have one good face. Warped, twisted, or spalled brick cannot be used.

Kiln marks are found on many good brick, but if these are not too deep and the brick has one good face, it may be used.

Checks that are serious enough to indicate careless burning, too rapid cooling, or poor material, are a cause for rejection of the brick.

Laminations, as has already been explained, are an indication of poor quality, and if serious are, therefore, a cause for rejection of the brick.

Summary of Requirements for Paving Blocks.[1]—"The brick for the roadway must be number one pavers, the size to be not less than 3 by 4 by 8 in., nor more than 3¾ by 4 by 9 in. In width and thickness they must not vary in size to exceed ⅛ in. They must be thoroughly annealed, tough, durable, and evenly burned. When broken, they must show a dense, stone-like body, fairly uniform in color and free from lumps of uncrushed clay, lime or air pockets, and show but slight laminations. Kiln marks or surface cracks must not exceed 3⁄16 in. in depth. The brick must be straight, and no bricks distorted so as to lie unevenly in the pavement may be used." If the edges are rounded the radius must not exceed ⅛ in.

CONSTRUCTION OF BRICK PAVEMENTS

The brick pavement is almost universally designed with a Portland cement concrete base. Under some conditions the macadam base or the base of No. 2 vitrified brick may be used, but the instances where either of these methods is economical are very much in the minority. For the concrete base good materials should be used, and ample thickness be provided, but the requirements for the concrete materials are not as

[1] Specification of Illinois Highway Department, 1915.

rigid as for those used in the concrete road or pavement. It should be noted that the base is used only to transmit the load to the earth subgrade and in so doing distribute it over sufficient area to insure stability.

Earth Subgrade.—The earth foundation upon which the concrete foundation rests is known as the subgrade or roadbed. It is apparent that it must be carefully prepared and well drained. After the pavement is completed, surface water will be cared for in pipe drains and will have no opportunity to percolate to the subgrade or roadbed. But usually the pavement lies low in the street and below the level of the parkings, and lawns alongside. Some underground water will, therefore, be likely to work under the foundation, but the amount usually is insignificant. With porous soils and unfavorable topographical conditions the subgrade may become water-saturated and unstable. When it appears that such may be the case, underground drainage must be provided. Frequently storm-water sewers, or sanitary sewers along the street will afford sufficient drainage, but in other instances tile drains must be laid. These usually are laid just back of the curb line and at a depth of 4 to 6 ft. In all doubtful cases the tile is advisable. For country brick roads the drainage must be taken care of as faithfully as if the road were to have no hard surface, and the principles involved have been discussed in Chapter III.

The subgrade is brought to the proper elevation and cross-section by excavating or filling as the case may be. If fills less than 2 ft. deep are constructed, they are built up in layers of not to exceed 6 in. in thickness, and each layer is rolled before the next is placed. For satisfactory results the soil must be moist when it is rolled. Where cuts are made it is advisable to plow within 2 or 3 in. of the subgrade grade and then roll to compress the subgrade to the proper elevation. The exact amount that the subgrade can be compressed varies with the type of soil and its condition, but it can readily be determined for each particular instance. A roller weighing 8 to 10 tons should be used for compacting the subgrade.

When finished, the surface of the subgrade should be true and smooth and so compact that the roller makes no perceptible track upon it. Unevenness in the subgrade means inequalities in the thickness of the concrete base, and since the base is often

but 4 in. thick, any high places in the subgrade will reduce the thickness of the base to a point that makes failure imminent.

Concrete Base.—The foundation or concrete base, as it is commonly called, should be made of good sound stone, whether limestone or some harder variety is used. The size of the stone may be from 2 in. down, but in practice, material larger than 1½ in. is rarely used. The sand may be any clean, siliceous or equally durable material and should be well graded from ¼ in. down. The Portland cement used should be a standard brand passing the tests usually specified for this material. The mixture may be 1 part cement, 2½ parts sand, and 5 parts stone, or 1 part cement, 3 parts sand and 6 parts stone, depending upon the character of the subgrade and the thickness specified. Since the concrete base is often made thin, it should be of reasonably good quality and the 1-2½-5 mixture is usually preferable to the leaner mixture. The use of bank gravel ought to be avoided, but if it must be used the mixture should be such as to maintain with the sand in the gravel the mortar strength ordinarily prescribed, *i.e.*, 1 to 2½. The following table indicates the amount of cement that will be needed with bank gravels of varying sand content, and illustrates the extravagance of using them, especially if the gravel contains more than 50 per cent. of sand:

TABLE 14.—SHOWING AMOUNT OF CEMENT TO USE WITH BANK GRAVEL

Percentage of sand by measure	Sacks cement per cubic yard of concrete
42 (ideal proportions)	5 0
50	5 9
60	7 0
80	9 2

Besides being uneconomical, the use of bank gravel should be discouraged because of the inevitable variation in the grading and the consequent variation in the quality of the concrete produced.

The thickness of the base for the brick pavement will depend upon the class of traffic and the nature of the soil. For heavy traffic and average soil conditions, the base should be 5 in. thick; for moderate traffic and ordinary soils, the thickness of the base is reduced to 4 or 4½ in. Probably it is unwise to use the 4-in. base except where very good soil is found and where good workmanship is assured so that the thickness will everywhere

be very close to that specified. With poor foundation conditions, the thickness of the base is made as great as 6 in. Much emphasis is placed on the necessity for good foundations by all authorities on brick paving, and it is much better to use too great a thickness than to use too little.

Thin-section Concrete Base.—For country road construction the cost of the pavement becomes a serious consideration, and the thickness of the base is reduced as much as is consistent with stability. It appears certain that country roads will be constructed with the base 3 in. or less in thickness. If that is

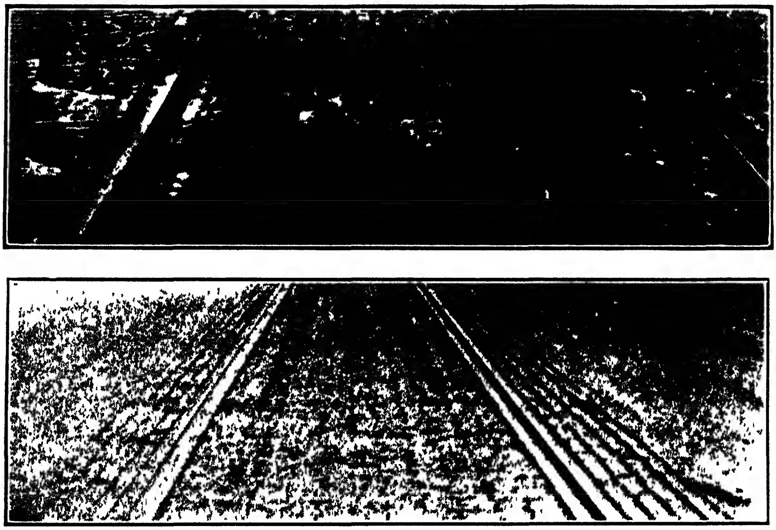


FIG. 51.—Methods of laying vitrified brick along car tracks.

attempted, two facts must be borne in mind. The earth foundation must be shaped with exactness so that the concrete will be uniform in thickness. The concrete must be of extra good quality such as is afforded by a 1-2-4 mixture. Probably on good soil, carefully rolled, with good concrete and good workmanship, the thin foundation will prove adequate for country-road traffic, but it is a doubtful expedient for general conditions.

Whatever may be the thickness or mixture used for the base, it should be finished carefully so that no porous places remain, and there are no protruding stones. The excellence of European block pavements has been frequently noted, and is believed to

be due in a large measure to the thickness of the concrete foundation and to the care with which it is placed and finished.

Base with Integral Curbs.—For rural highways the roadway is constructed with curbs designed merely to hold the brick in place and protect the edge of the pavement. The curb is built flush with the surface of the brick instead of extending above it as it does on a street pavement. This curb is constructed integral with the base, and either of the same mixture or of a richer mixture, the latter being preferable. For best results, the curb should be a 1-2-4 mixture. Usually it is 6 in. wide. This type of base is shown in Fig. 50.

Macadam Base.—Where concrete materials are expensive (sand and cement), and limestone is available, the base for the brick pavement is made of 6 or 8 in. of water-bound macadam. On good soil, this type of foundation will prove adequate if it is well constructed, but can never be as satisfactory as the concrete base. Such a base is constructed just as water-bound macadam surface would be (see Chapter VIII).

Two-course Pavements.—The base for the brick pavement is sometimes made of a layer of No. 2 vitrified brick laid flat. The subgrade is prepared as for the other kinds of base, and the layer of sand 2 in. thick is spread on it. On this a layer of No. 2 brick is laid flat and rolled with a 4-ton roller. This type of base is economical only when the No. 2 brick can be purchased at a low price, and when concrete materials are relatively expensive.

Sand Cushion.—The sand cushion affords a means of bedding the brick so that the upper surfaces will conform to the pavement surface, and serves as a means of taking out any unevenness in the foundation.

Obviously the bricks will not all be exactly of the same depth and some will have slight imperfections, such as kiln marks or slightly warped faces. These defective faces are placed down when the brick is laid. In laying the brick there will be some unevenness due to inevitable differences in skill of workmen. When the brick surface is rolled the lower face is bedded into the sand until the upper face comes even with the other brick in the surface and thus a smooth pavement is secured. For this purpose the sand cushion need not be to exceed 1 in. thick. But some lack of uniformity in the base is inevitable, and the sand cushion must equalize it. Therefore, while the minimum thickness

of the sand cushion is about 1 in., 1½ or 2 in. is more commonly employed. The wider the pavement, the more difficult it is to keep the surface uniform, and the more likely it is to require considerable thickness of the sand cushion. The sand cushion is a weakness in any case, and should be kept as thin as consistent with proper bedding of the brick.

The sand should be reasonably coarse and fairly clean, but the requirements are not as rigid as for sand for concrete purposes.

Sand-mortar Cushion.—If car tracks exist on a street, the constant vibration has a tendency to loosen the brick near the rails, and to afford openings that will let water down to the sand cushion which will work toward the curbs, carrying the sand with it. The track will be forced down by the weight of the cars and will spring back up after the cars pass, pumping the water in and out, and this also tends to force water through the sand cushion and to displace it. The vibration from traffic tends to shift the sand cushion when it is dry, resulting in hollow places under the brick surface.[1] To overcome these tendencies a mortar composed of 1 part cement and 3, 4 or 5 parts of sand is now being used. The sand and cement are mixed dry and spread for the cushion and the brick are laid and rolled. The pavement is then sprinkled lightly and the water penetrates the cushion in sufficient quantities to cause the cement to set. A cushion of this sort is generally recommended for streets on which there are car lines or where for any other reason there is a possibility of the pavement being broken so as to permit the entrance of water into the cushion. It is rapidly replacing the ordinary sand cushion.

Placing the Sand Cushion.—The sand is spread on the base in a layer about ½ in. thicker than the cushion is to be. Strips of wood of the thickness of the finished sand cushion are placed first on the base near the curb and at the crown, and on top of these a second set of strips ½ in. thick is placed. The sand is struck off by dragging a screed along these strips, thus spreading the sand to the thickness of two strips combined. The screed is cut to the proper cross-section and the cutting edge is shod with a metal plate. If the pavement does not exceed 25 ft. in width, the screed may be constructed to span the entire width of the pavement, but for wider pavements it is better to span half the width.

[1] Mr. Mont Schuyler in *Engineering Record*, July 3, 1915.

After the sand has been struck off, it is rolled with a hand roller about 30 in. long and weighing about 15 lb. per inch of length. When the cushion has been thoroughly rolled, the ½-in. strips are removed and the screed is drawn along the remaining strips and thus the well-packed sand is trimmed to exact thickness. The sand is most readily handled if it is in a moist condition, this being better than to have the sand either very wet or very dry.[1]

Where the sand-mortar cushion is used, it is placed in exactly the same way, except, as before noted, it is handled dry.

Laying the Brick.—The brick are laid in straight rows at right angles to the center line except at intersections

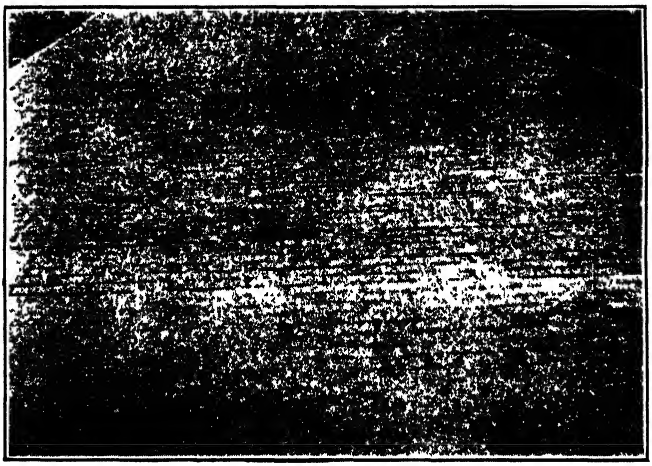


Fig. 52.—Brick surface showing skilled laying.

where they are either laid parallel to the diagonals of the intersection, or by the herringbone pattern. The end joints in each row are placed opposite the middle of the bricks in the adjoining rows and part bricks are used only in starting rows and making closures. The bricks are placed with the best face up and the lugs all in the same direction. After five or six rows have been placed, they are closed up by driving with a maul. This is done to make the cross-joints as close as the lugs will permit.

[1] See No. 1 Specifications, National Paving Brick Manufacturer's Association.

After the brick have been laid, the chips and spalls are swept off the surface which is then inspected and all defective brick are replaced with good brick. An example of skilled laying is shown in Fig. 52.

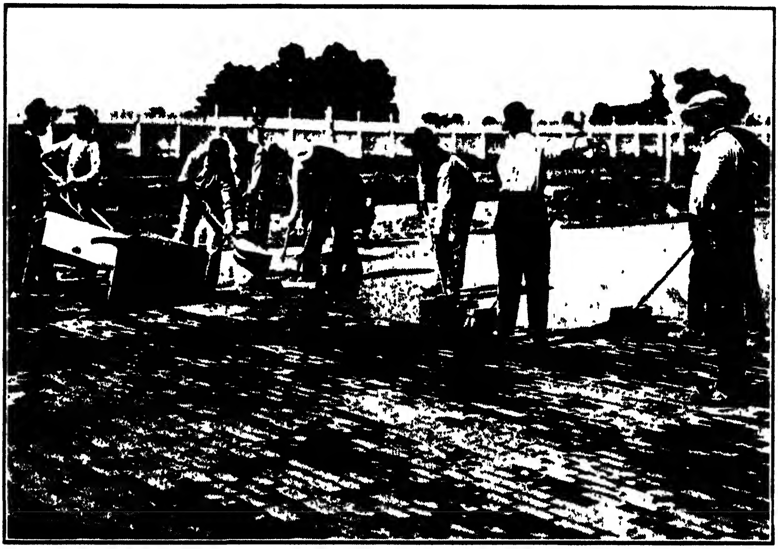
Rolling the Brick.—The brick are then rolled with a tandem roller weighing between 4 and 6 tons. The object of the rolling is to bring all the brick to a true surface, individual bricks being adjusted by being pressed into the sand cushion under them. If any are too low they are detected and raised by removing them and adding a little to the sand cushion. The rolling is started at the curb, the roller moving parallel to the curb and gradually working to the crown. The roller is then taken to the opposite side of the street and the operation repeated. After the first rolling, the surface is again inspected, and all broken or spalled brick removed and replaced. The brick are again rolled, this time diagonally across the pavement, first in one direction and then in the other. Sometimes a final rolling parallel to the curbs is required. The brick cannot be rolled, if the sand cushion is wet, without forcing the sand up between the brick to an extent that will interfere with the penetration of the filler.

If the dry mortar cushion has been used, the surface is sprinkled after the rolling to furnish water for the cushion, providing the bituminous filler is used, but if the cement grout filler is to be used the sprinkling is done just before the grout is poured.

Fillers for Brick Pavements.—Sand, bituminous cement and Portland cement grout are each used for filling the joints between the brick. A suitable filler serves to bind the brick together so they will not be disturbed by traffic, supports the upper edge of the brick so as to reduce the abrasion and closes up the surface so water and street liquids cannot penetrate to the sand cushion.

The Sand Filler.—Sand filler is permissible only when the traffic is light. It does not bind the brick together and furnishes only partial support against displacement. It does not support the upper edge of the brick against abrasion and only partially closes the joints against street liquids. When the rolling has been completed, the surface of the pavement is covered with sand which is swept into the joints. A surplus is left on the surface which either works into the joints or is washed off by rains.

The Grout Filler.[1]—The cement grout filler unites the surface into a monolithic layer, and, if properly applied, will be flush with the tops of the brick and thereby protect the edges against abrasion. If the grout is of poor quality it will be chipped out of the joints by iron-shod horses and leave the edges exposed. The object of the filler is to make the pavement monolithic and so unite the brick units that the wear on them will be no more than that of friction and grinding.



Courtesy of Mr. Will P. Blair.

FIG. 53.—Applying grout filler to brick pavement.

The filler should be composed of 1 part each of clean, sharp, fine sand and Portland cement. The sand should be dry. The mixture, not exceeding one sack of the cement, together with a like amount of sand, is placed in a box and mixed dry, until the mass assumes an even and unbroken shade. Water is then added, forming a liquid mixture of the consistency of thin cream.

The sides and edges of the brick should be thoroughly wet by sprinkling before the filler is applied.

From the time the water is applied until the last drop is removed and floated into the joints of the brick pavement, the

[1] From No. 1 Specifications, National Paving Brick Manufacturers' Association.

mixture must be kept in constant motion. Long-continued mixing is essential.

The mixture is best removed from the box to the street surface with a scoop shovel, the mixture in the box being continuously stirred as it is emptied.

The box recommended for this purpose is 4 ft. 8 in. long, 30 in. wide and 14 in. deep, resting on legs of different lengths so that one corner will be lower than the others. The mixture will readily flow to the lower corner of the box, which is not to be more than 6 in. above the pavement.

Two such boxes are to be provided in case the street is 20 ft. or less in width; if it exceeds 20 ft. in width, three should be used.

The mixture the moment it touches the brick should be thoroughly swept into the joints.

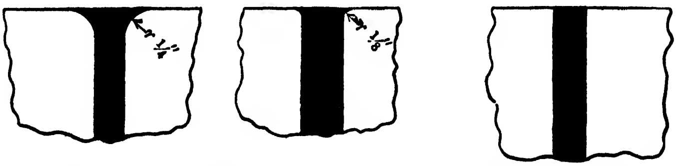


FIG. 54.—Cross-sections of joints between paving brick.

The work of filling should be carried forward in line until an advance of 15 to 20 yd. has been made, when the same force and appliance are turned back and cover the same space in like manner, except that the mixture shall be slightly thicker for the second coat.

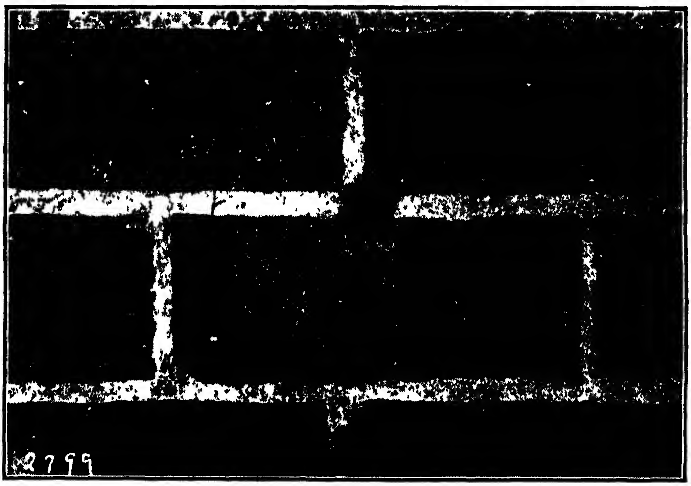
To avoid the possibility of thickening at any point, the surface ahead of the sweepers and ahead of the mixture should be gently sprinkled, using a sprinkling can the head of which is perforated with small holes.

Any attempt to thin the mixture on the pavement by the application of water will result in the separation of sand and cement and "bad spots" will appear in the pavement where this practice has been permitted.

After the joints are thus filled flush with the top of the brick and sufficient time for hardening has elapsed, so that the coating of sand will not absorb any moisture from the cement mixture, ½ in. of sand is spread over the whole surface, and in case the work is subjected to a hot summer sun, the sand should be

sprinkled lightly for 2 or 3 days. The street should be kept closed for 10 days in warm weather, and a longer time if the weather is cool.

(*A*)



(*B*)

FIG. 55.—Comparison of pitch and cement grout fillers. (*a*) Pitch filler. (*b*) Grout filler.

Pouring Bituminous Filler.—When a bituminous filler is used instead of a cement grout filler, the pavement is completed in the same manner as when the grout filler is used, up to the point where the filler is applied. Bituminous fillers must be poured

into the joints at a temperature sufficient to insure adhesion to the brick. This varies with different classes of materials, but usually is about 400°F. for asphalt fillers and about 250°F. for pitch fillers. The device which is used for pouring the filler consists of a cone-shaped vessel having at the point a cast-iron tip with an opening about 1/4 in. in diameter. The pouring can is drawn along the crack between the rows of brick, the point resting in the crack. The opening in the point is controlled by means of a valve with a handle conveniently arranged so that the flow of the bituminous material can be adjusted. As the vessel is drawn along, the bituminous material is allowed to flow out into the joint in sufficient quantity to fill it. A helper replenishes the supply in the pouring can from time to time so that the pouring goes on continually. Recently there have been developed pouring cans with multiple spouts which pour several joints at one time. These are mounted on wheels and are drawn across the pavement with each of the points in the joint between two rows of brick. A steering device attached to the point serves to retain it in the joint. A slight excess of bituminous material is usually put in the joint, but this wears down flush with the brick in a short time.

In connection with the use of the filler, attention is called to a fact already mentioned, viz., that some kinds of brick have a rounded edge while others have a square edge. With the rounded edge the filler must extend back from the joint to a thin edge, while with the square-edge brick the filler does not extend beyond the width of the joint. This is illustrated by Fig. 54. The thin edge is quite likely to wear away quickly and is to be avoided.

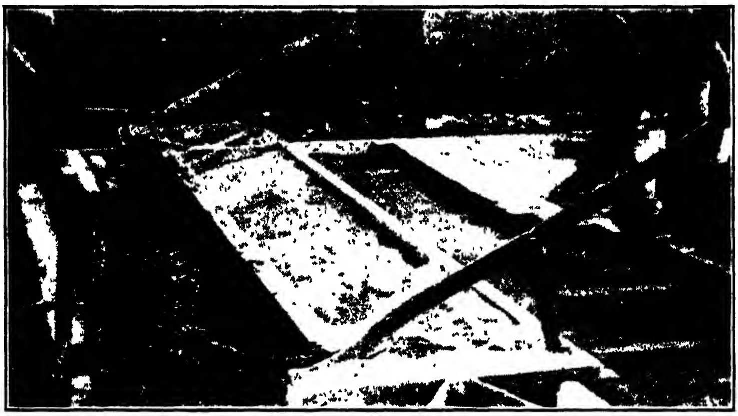
Expansion Joints.—The object of using the expansion joint is to take up the change in dimension of the pavement following temperature changes. It is, therefore, important on street pavements to provide for ample expansion along both curbs where the joints should not be less than 1/2 in. wide, for streets over 14 ft. wide, and not less than 1 in. for streets between 25 and 40 ft. wide.

Opinion differs as to the advisability of transverse joints. It seems to be well established that they are unnecessary and that the expansion will merely produce compression in the brick surface. This, of course, is impossible crosswise of the pavement, because the curbs do not afford sufficient support.

Recent practice is to omit the transverse joint. When used, it is common to use a ½-in. joint about every 50 ft.

There are several prepared joint fillers such as the Carey elastite filler and the Genasco asphalt filler which consist of sheets of a bituminous material of the requisite width and thickness to fill the joints. This filler is set in place before the brick are laid.

Filling Expansion Joints.—The expansion joints along the curbs and those transverse to the pavement are formed by slightly wedge-shaped strips of wood which are placed in position before the brick are laid. Shortly after the cement grout is poured, these wooden strips are pulled out of the ex-



Courtesy Mr R. L Bell.

FIG. 56.—Special template for monolithic brick road construction.

pansion joints and the space filled with bituminous material of the same character that would be used for filling the joints between the brick. In some cities a mastic composed of equal parts of bituminous material (usually asphalt) and sand is used for expansion joints. The bituminous material and the sand are heated separately and then mixed on a heated metal platform and while in a plastic condition tamped into the joints.

Whatever type of filler is used for expansion joints, precautions are taken to insure that it shall extend entirely through the pavement and particularly that it shall be flush with the top of the pavement. When the prepared expansion joint fillers are used they are, of course, placed in position prior to the laying of the brick, and require no further attention.

COUNTRY BRICK ROADS

Design.—In the construction of brick roads for country traffic all of the general principles must be observed that have been discussed in connection with brick pavements. The width is usually 9 ft. for single-track roads and 18 ft. for double-track. The units that make up the traffic on the average country road are neither so numerous nor so heavy as those encountered in the city, and the base is sometimes made of less thickness than for city pavements. Frequently it is made about 4 in. thick. It is comparatively easy on these narrow pavements to strike the concrete base with a templet to the exact cross-section desired, and it therefore becomes unnecessary to use a sand cushion more than 1 in. thick.

Since the country road is narrow, traffic will continually pass from the brick surface to the earth road alongside; therefore, the curbs used to retain the brick pavement at the edge are made level with the brick surface instead of extending above as with city pavements. The curbs are usually monolithic with the base.

The transverse expansion joint is commonly omitted from country roads. The transverse cracks which form as the pavement contracts will be of little significance under the class of traffic encountered. The longitudinal expansion joint is placed along one curb and prevents the pavement from arching under temperature changes and prevents the brick surface from breaking the curbs from the base.

The use of the cement grout filler is recommended and the construction of the pavement is carried out as carefully as the first-class city pavements and with materials of the same quality.

Monolithic Brick Pavements.[1]—The monolithic type of brick pavement is constructed by laying the brick wearing surface directly on a freshly placed concrete base and rolling the brick to bed them in the concrete before it takes a set.

The general design and the requirements for materials are the same as for any other high-class brick pavement. When constructed on a country road no marginal curb is used.

It is recommended that the concrete base be 4 in. thick for moderate traffic conditions, but there seems to be no reason why

[1] Data furnished by Mr. R. L. Bell, District Engineer, Illinois Highway Commission.

See also *Engineering Record*, July 10 and July 17, 1915.

it need be more than 3 in. thick for country roads of light or moderate traffic. For city pavements 5 in. is sufficient for the severest conditions for which the brick surface is suitable.

The subgrade is carefully prepared and thoroughly rolled and during the construction the wagons hauling aggregates are kept on the side of the road as much as possible if on a country road. The roller is kept at work on the subgrade smoothing out the wheel tracks that are made by the wagons when they turn in on the subgrade to deliver concrete materials.

The concrete is mixed to a plastic consistency and struck off to the proper cross-section by means of a special templet which is a feature of the construction equipment that has already been developed for this particular type of pavement. It is shown in Fig. 56.

The templet consists of one I-beam crossbar and one channel crossbar spaced about 2 ft. apart and supported on the steel side forms by means of rollers. The templet is drawn along the side forms by the mixer. The forward member of the templet cuts the concrete base $\frac{3}{16}$ in. below the finished grade and dry mortar of 1 part cement and 5 parts sand is spread over the concrete ahead of the rear bar of the templet. This dry mortar is spread over the base by the rear part of the templet and the brick are laid directly thereon.

The setters place the brick carefully with the best side up and the lugs all in the same direction, and while the laying cannot proceed quite as rapidly as on the sand cushion, probably under favorable conditions a laborer can lay three-fourths as many per day as he would on a sand cushion.

The carriers who deliver the brick to the setters walk over the brick already laid and apparently do not disturb them, although as a precaution a 1-in. plank is laid over the brick where the carriers first step onto the newly laid surface. The bats are cut and set as fast as the courses are completed so that the surface is kept finished up close to the setters.

As fast as the laying is completed, the surface is rolled with a hand roller about 30 in. in diameter and 30 in. long and having a weight of about 600 lb. The rolling irons out the little irregularities of the surface and beds the brick slightly in the dry mortar on the concrete base.

The surface is grouted in the manner described in this chapter for the brick surface on a sand or mortar cushion.

It will be noted that the feature of this construction is that the brick are laid directly on the concrete base before the concrete hardens. A thin mortar layer is used merely to smooth the surface of the base.

This type of construction has the following advantages over the type in which the sand cushion is employed:

1. It is at least 10 cts. per square yard cheaper.
2. It eliminates the trouble experienced in rolling if a rain comes on before the rolling is done.
3. It insures a firm support for each brick.
4. It eliminates the danger of sand squeezing up into the joint and preventing the proper penetration of the grout filler.
5. It eliminates the necessity for the marginal curb on country roads.

APPLIANCES USED

Grading Appliances.—The grading is done with the tools and appliances which have already been discussed in connection with earth roads. The particular combination suitable for each individual piece of work varies somewhat; but the elevating grader and dump wagons are often used for the rough grading and the blade grader and hand tools for finishing.

Rollers.—The macadam roller weighing 8 to 10 tons is used for the subgrade and the tandem roller weighing 4 to 6 tons for the brick surface. The single roll drawn by horses is sometimes employed, but is not quite as satisfactory as the power-driven roller.

Mortar Box for Grout.—The special type of grout box recommended by the National Paving Brick Manufacturing Association is used for this purpose almost exclusively.

Carriers for Brick.—Brick are carried from the piles to the setters by means of clamps holding about six brick and operating on the familiar principle of the ice tong. These are also used for handling the brick at the cars. Rolling carriers are also used to convey the brick from the piles to the setters. These consist of a series of rollers set in an inclined frame and the brick move by gravity down the incline.

Concrete Mixers.—The mixers used are of the same general types that are used for concrete road work. In addition the stationary type is often used, being set up at the end of the block and the concrete being conveyed in carts to the work, but the

limit of haul is about 350 ft. if segregation of the aggregates in the concrete is to be avoided.

CHARACTERISTICS OF BRICK PAVEMENT

The brick pavement affords a rigid surface having good traction for motor vehicles and fairly good footing for horses. It has a pleasing appearance if well laid and is sanitary and very durable. It is rather noisy under horse-drawn traffic, especially if grout-filled. It is reasonably easily opened for repairing service pipes and repairs are readily made. It must be kept scrupulously clean to avoid dust as the particles will not cling to the surface.

Cost of Brick Pavements.—The cost varies somewhat in different communities, and yet the range is not great. On city streets brick pavements cost from $1.75 to $2.25 per square yard of surface, exclusive of the heavy grading and exclusive of the cost of curbs. On country roads the cost where the haul does not exceed about 2 miles is usually estimated at $1,000 per mile per foot of width of pavement.

EXAMPLES OF GOOD PRACTICE

Details of Construction which make Brick Pavements Good or Bad[1]

The importance of details as factors of good-roads construction is emphasized by the brick highways in Erie and Niagara Counties, New York, which were inspected during the recent annual convention of the National Paving Brick Manufacturers' Association, at Buffalo. Good construction, bad construction and intermediate grades were exemplified. Different kinds of brick, and different makes of the same kind of brick have been used, but while the brick highways range in quality from bad to perfect the differences among them are not wholly attributable to variations in the quality of brick. Both good and bad roads are built of the same kind and make of brick, and sometimes the same contractor built both kinds or roads with one kind of brick.

A noticeable distinction between types of brick was found in the fact that even on roads of inferior construction the sections

[1] Will P. Blair, Engineering Record, Nov. 7, 1914.

laid with square-edge brick were uniformly better grouted than were sections of the same roads laid with round-edge brick, although instances of faulty grouting occur with both types of brick.

Damage at Expansion Joints

The contractor has not been at fault in all cases, although his sins of omission and commission are many. The worst roads are those having cross-expansion joints. Pavements otherwise in good condition show courses of broken and sunken joints at regular intervals of 50 ft. on account of transverse expansion joints. In some instances courses of brick on each side of the cross-expansion joint are broken. But cross-expansion joints were specified, and the contractor was obliged to put them in.

The best pavements, and the only perfect pavements, were those having longitudinal expansion joints only, although not all pavements having longitudinal joints were found in good condition. It can, however, be affirmed, without fear of successful contradiction, that neither in Erie County nor in Niagara County was there seen a cross-expansion joint pavement in perfect condition after 2 years of service. On some highways, notably road No. 2 running out of Hamburg, cross-expansion joints and longitudinal expansion joints occur in different sections of the same road; but in every instance cross-expansion joints show at a great disadvantage.

Grouting and Rolling

The visitors received ample proof that a perfect brick highway can be laid and that it will remain unimpaired under traffic conditions for years. The reverse of the picture was exhibited as well. Slipshod methods of construction have been responsible for poor pavements. Faulty foundations and poorly prepared sand cushions are accountable for some defect, but by far the most prolific cause of poor pavements—excepting cross-expansion joints—is poor grouting. Poor material and materials mixed in wrong proportions contribute to poor surfacing, but as a rule either ignorance or carelessness in applying the grout is the source of failure. Too much care cannot be exercised at this stage of construction, but observation teaches that some contractors attach little importance to the details of grouting.

A tour over construction work discovers another cause of poor pavement in the laying of long stretches of brick ahead of rolling and grouting. This method is destructive in case of rain, as brick on a wet sand cushion cannot be rolled without forcing the sand up between the joints. This disrupts the smooth, compacted bed upon which the brick rest and the sand between the bricks prevents the bonding material from penetrating to the bottom of the courses and forming a strong bond. Brick rolled on a wet sand cushion will rock, nor can a smooth, even pavement be made with a wet sand cushion under it. Contractors are not ignorant of these facts but they take chances and sometimes, unless closely watched by the engineer in charge, they grout over a pavement laid on a wet sand cushion and cover up their folly temporarily. It saves taking up the brick and relaying them. It is easy to uncover such fraudulent work by pulling out a brick here and there and noting how far the sand has been forced up by rolling of the brick.

All work should be rolled before leaving it at night. The roller should follow the pavers closely and the grouters should keep as close to the roller as practicable, closing up the work each night. Yet sometimes engineers permit contractors to lay a quarter of a mile or more of brick ahead of the grouters.

Two evils arise from this course—first, the danger of rain on the sand cushion; second, the mixing and the dumping of too much filler at one time in order to rush the work. Unless closely supervised grouters will mix batches too big, and they will put enough grout on the pavement to grout 15 ft. instead of the maximum permissible limit of 5 ft. The inevitable result of mixing batches that are too big is, separation of sand from cement and consequent weakening of the bonding material. Bridging of joints is another peril from dumping grout on the pavement.

Proportioning Grout

Another observed tendency of grouters is to mix the final coat of grout too thin or too thick. If too thick, the grout bridges the joint; if too thin it settles in the joints instead of setting flush with the pavement. The general tendency is to mix the first grout too thick and the final course too thin. The final grout should be somewhat thicker than previous courses, but it should not be too thick nor should too much of it be put on at

one time; it is imperatively necessary not only that the batch be kept thoroughly mixed but it must be thoroughly squeegeed into the joints. In one instance workmen were observed thinning grout by pouring water on it on the pavement, thereby separating the constituent elements of the grout and destroying its efficiency. This fault was corrected, but there is reason for believing that that method of thinning grout is somewhat general. The right way, therefore the only way allowable, is to thin in the grout box and keep constantly stirring.

Contractors and engineers, unless thoroughly experienced in highway work and conscientious in their work, are prone to neglect or slight what appears to be minor details, nor in their methods do they always discriminate between the two kinds of brick commonly used for paving.

Method of Finishing Grouting

The method of finishing the grouting of a brick pavement differs with the type of brick used. The final course of grout on a round-edge brick pavement should be squeegeed until the surface of the pavement is as nearly as practicable free from grout; otherwise, when the excess grout breaks under the pounding of traffic and comes off, it will pull portions of the grout from the round-edge joints. No such danger from a heavy surface coating of grout menaces a pavement laid with square-edge brick. The square edges of the brick protect the joint and the excess of grout comes off the pavement without impairing the grout at the joint. The difference between round-edge brick and square-edge brick in respect to the final grouting is this: Whereas in the case of the former all surplus grout ought to be squeegeed off the pavement, in the case of the latter the surplus may be taken off or left on without deleterious effect. The objection to leaving a thick covering of grout over the pavement is that it is unnecessary and, therefore, wasteful.

The tour of the brick roads of Erie County disclosed the fact that in some instances the failure of contractors properly to protect the freshly grouted pavement with a blanket of moistened sand had resulted in too rapid setting of the filler. The result was "crazing" and pin-cracking of the grout. The same condition was found on the Kennilworth Avenue pavement recently laid by the city of Buffalo.

Laying the Brick

Brick laid with lugs the wrong way brought together two smooth sides of adjoining brick, thereby preventing the penetration of filler and preparing the way for defective spots in the completed pavement. Such faults are the result of inexcusable carelessness, but competent engineers and inspectors detected them in time to forestall serious consequence.

Another indication of neglect to follow specifications was observed in the placing of the uneven or broken edges of bats next to the curb. This is not, perhaps, a serious structural defect, yet it is both aesthetically and practically wrong. It detracts from the symmetrical appearance of the pavement at the sides by giving it a rough, uneven edge, and it deprives the pavement of the extra bonding strength afforded by union of the filler with the rough surface of the bat. Some persons may regard these strictures as hypercritical, but no detail of construction is negligible. A good pavement represents the homogeneous aggregate of all constructive details properly wrought out.

Foundation Drainage

The necessity for proper drainage of foundations was strongly impressed upon the observers of brick highways in Erie and Niagara Counties. There are miles upon miles of pavements without cracks, sunken spots, broken bonds or other noticeable defective features, yet several highways show cracks and sunken spots unquestionably due, in the first instance, to ineffectual drainage. While it is probably true that longitudinal cracks sometimes result from causes other than defective drainage, a well-constructed foundation, properly drained, is a sure preventive of sunken spots in a pavement, nor are cracks likely to occur unless moisture is taken into the foundation either by direct contact or by capillary attraction.

The tour of inspection around Buffalo found apparent evidence of negligence in the matter of drainage, but conclusive proof was adduced that a well-drained and well-constructed grouted brick pavement is impervious to surface water. Portions of the brick boulevard running from Buffalo to Niagara Falls were submerged by the flood a couple of years ago, for a period of 2 or 3 weeks, yet they were absolutely unharmed and were

marked neither by cracks nor depressions, nor by broken bonds. Damage to brick pavements resulting from moisture originates beneath the foundation. That the problem of drainage can be solved even under adverse natural conditions is a fact which was demonstrated on the tour.

Cull Brick

For almost its entire length of 23 miles the boulevard between Buffalo and Niagara Falls runs through a level country, and the same is true of the highway between Lewiston and Youngstown. Yet in the former only a few bad spots exist, and in the latter none at all. The worst spots on the boulevard are attributed to the use of cull brick. This brick, it is alleged, was condemned in Niagara County, but by some means the culls found their way across the line into Erie County and were placed in the pavement at two points. It might be an idle waste of time to speculate on the sequence of events which eventuated in the translation of brick from a cull pile in one county to a snug place in a state boulevard in the county adjoining, but it is only fair to say that the manufacturer who furnished the brick says he received cull prices for the cull brick and was not cognizant of the high testing which awaited them. Without attaching to the incident any remote significance, the incident does emphasize the need for close supervision of construction work by engineers in charge, and it puts an acute accent on the necessity for honest, capable and diligent inspection. Eternal vigilance is the price of a good pavement.

Inspection

Poor judgment of the qualities of brick is a weakness not infrequently found in inspectors. Among culls thrown into the discard by inspectors on construction work were found what practical men declare to be the very best brick in the shipment. Conversely, some of the brick that were passed were of inferior quality. Without making any specific application to individuals, or to any particular job, it is safe to affirm that inspection of brick on the roadway is to some extent a matter of individual preference, and in many cases inspectors are not qualified by experience or by native ability to judge correctly

of the quality of brick by its appearance. The result is an almost total absence of uniformity in standards of judgment and an insistent demand for a better system, or at least for expert inspection.

There does seem to be among inspectors a common prejudice against brick of a dark shade, although it is quite possible that such brick may be exceptionally durable. The shade is not always an indication of overburning. The inspection of brick is often delegated to persons selected without regard to their fitness for the duty; and brickmakers may be mulcted from 2 to 3 cts. per brick on large consignments by the ignorance of inspectors appointed for political reasons or for other reasons equally obnoxious. Nor is the abrasion test always fair to the brickmakers.

These reflections and comments are based upon observations made on old and new work in a recent tour of 200 miles over highways in Erie County and Niagara County, New York.

CHAPTER XI

WOOD-BLOCK PAVEMENTS

Wood-block pavements have been used in Europe for many years, and for at least 40 years in the United States. The earlier types were made from blocks sawed from round logs and laid as closely as their shape would permit. They were not treated with any kind of preservative and consequently the life was short and the pavement was rough, due to the shape of the blocks and the method of laying. The later developments produced a pavement made up of blocks cut to a rectangular shape so as to lie closely and evenly in the pavement. The wood was impregnated with a preservative and was more durable than any of the earlier pavements. In the last few years this type of pavement has come into very wide use, both in Europe and America.

SIZES AND KINDS OF BLOCKS

Kinds of Timber Used.—In the United States, southern long-leaf pine, short-leaf pine, red gum, tamarack, Douglass fir and Norway pine have all been used for the blocks. Probably three-fourths of the blocks laid, however, are made from southern long-leaf yellow pine. In this connection, the term long-leaf pine is used to designate quality rather than species and short-leaf pine of sufficiently dense structure would be acceptable as well as the long-leaf pine. Abroad, short-leaf pine, white pine, redwood and fir are used principally, although Australian hard-wood is used to some extent.

Of the timber available in the United States it is generally conceded that the southern long-leaf yellow pine is the most durable. It is, however, a hard wood and consequently the pavement in which it is used is likely to be more slippery than one constructed of some of the softer woods. Where traffic conditions are not severe and in parts of the country where the yellow pine is not available, other timber, such as tamarack and fir, are used successfully.

The essential characteristics of the timber are uniformity of texture and ability to resist wear, adaptability to the preservative

treatment, and freedom from defects that will impair the life or wearing properties of the block pavement. Uniformity of texture is secured by specifying the minimum number of annual rings per radial inch in the block. Other defects are eliminated by inspection of the timber before it is cut into blocks and by inspection of the blocks during and after the laying.

Size of Blocks.—The depth of the block is varied to suit the traffic conditions, but in most of the pavements laid they have been either 3, 3½ or 4 in. deep, the last-named being used on the heavier-traffic streets. The width of the block is not important so long as it is not greater than about 4 in., and blocks made by various manufacturers vary from 2½ to 4 in. in width. The length of the block is equal to the width of the plank from which it is cut, and consequently varies in any lot. It should never be less than 5 in. nor greater than about 10 to 12 in. If the block is too short it will not sufficiently distribute the load that may come upon it, and if it is too long it will split under heavy loads, or not lie evenly in the pavement. All blocks used on any one contract should be of the same depth, except that sufficient variation must be permitted to allow for the uncertainties of manufacture. Usually specifications permit variations in depth of $\frac{1}{16}$ in. Likewise for convenience in laying, all blocks used in any one contract should be of the same width, except such variations as are incident to manufacture and this is limited to $\frac{1}{8}$ in.

Quality of the Blocks.—The blocks must be free from defects such as large or loose knots, wind shakes, heart rot and pitch pockets. It is always desirable that the block be composed largely of heart wood and specifications usually require that a certain percentage (varying from 65 to 80 per cent.) of the block shall be heart wood. To preclude the use of coarse-grained, second-growth wood or short-leaf pine of poor quality, the number of annual growth rings per radial inch should be at least six and at no place on the face of the wood should the number of such rings be less than four.

PRESERVATIVE TREATMENT

Character of Preservatives.—Wood blocks when used as a pavement surface are laid with the grain vertical. The block in this position will wear for a long time if the wood does not decay. The cause of decay is fungus growth in the wood, and

to prevent decay the blocks are impregnated with an antiseptic which will prevent fungus growth. The material most commonly used for this purpose is coal-tar creosote.

The wood used for block pavements possesses another characteristic that is of some significance in connection with the preservation treatment. Untreated wood will absorb considerable quantities of moisture and in so doing will increase in size very materially. Treated blocks will absorb some water but by proper treatment the quantity can be reduced to an

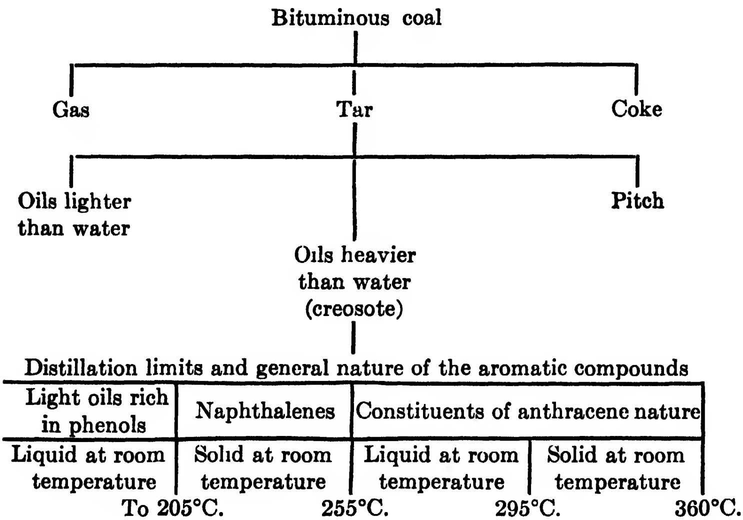


FIG. 57.—Source and composition of creosote oil.

amount so small as to obviate trouble from swelling. Excessive absorption of water has caused considerable trouble due to the difficulty of taking care of the expansion, especially on wide streets. Recent practice is to impregnate the blocks in a manner and with a material intended both to preserve and waterproof the wood. This is accomplished by using a mixture of creosote and tar.

Creosote Oil.—The preservative employed for wood blocks is creosote oil, a coal-tar distillate, or a mixture of creosote oil and tar. Pure creosote is a distillate of coal tar and its properties are represented by the following diagram:[1]

Pure creosote, therefore, consists of varying percentages of the four groups of compounds indicated in the above diagram.

[1] Weiss, "The Preservation of Structural Timber," p. 80.

Of these compounds the first group (phenols) is highly antiseptic and it is desirable that there be sufficient of these compounds mixed with the creosote to insure preservation. The second group (naphthalenes) is also antiseptic, but is also volatile at air temperature and will gradually leave the block by evaporation during the first years of the life of the pavement. The third and fourth groups (anthracenes) are not as highly antiseptic as the phenols, but are much less volatile and are insoluble in water, while the phenols are soluble in water. It is generally believed that the creosote oil used for paving blocks should contain a considerable proportion of the anthracenes. The specific gravity of a pure creosote oil obtained by the distillation of tar will be from 1.03 to 1.08 at 25°C. Generally speaking the higher the specific gravity the greater the proportion of the anthracenes in the creosote oil.

Mixtures of Tar and Creosote.—The commercial creosote oil employed for the preservation of wood-paving blocks frequently has a specific gravity greater than 1.08 and sometimes as great as 1.14. Such an oil is a mixture of pure creosote and tar. It is contended that an oil of this character contains sufficient pure creosote to preserve the blocks and that the admixture of tar serves to increase the waterproofing properties of the oil. It is not known that such an oil is a suitable preservative since it has not been in use for a sufficient time to demonstrate this point. It is known, however, that the presence of tar in the oil tends to increase the difficulties due to the blocks bleeding and that the presence of appreciable quantities of free carbon (soot) in the creosote oil is particularly objectionable.

Creosote Oil Specifications.—Two types of creosote oil are being used for the preservation of wood-paving block, the one a light practically pure creosote oil and the other a heavy creosote oil and tar mixture. The latter has been much more widely used than the former, but it is probable that the lighter oil will come into more extensive use in the future.

SPECIFICATION FOR LIGHT CREOSOTE OIL[1]

"Specific gravity at 38°C., 1.03 to 1.08.

When distilled in the standard manner[2] the creosote shall give distillate within the following limits, calculated in percentage of dry oil:

[1] No. 1 oil as specified by the American Railway Engineering Association.

[2] See description of method, p. 405.

To 200°C. no distillate.

To 210°C. not more than 5 per cent.

To 235°C. not more than 25 per cent.

The residue at 355°C. if it exceeds 5 per cent. shall be soft. The oil shall be a pure distillate of coke-oven tar or coal-gas tar without the admixture of any other material. It shall be completely liquid at 38°C., shall contain no suspended matter and shall contain not to exceed 3 per cent. of water.

SPECIFICATION FOR HEAVY CREOSOTE OIL[1]

The preservative shall be wholly derived from coal-gas tar or coke-oven tar, and shall comply with the following requirements:

The specific gravity shall not be less than 1.06 nor more than 1.12 at 38°C.

Not more than 3 per cent. shall be insoluble by continuous hot extraction with benzol and chloroform.

On distillation which shall be made exactly as afterwards described, the distillate, based on water-free oil, shall be within the following limits:

Up to 210°C., not more than 5 per cent.

Up to 235°C., not more than 30 per cent.

Up to 315°C., not less than 35 per cent., nor more than 70 per cent.

Up to 355°C., not less than 65 per cent.

The specific gravity of the distillate between 235°C., and 315°C., shall be not less than 1.02 at 38°C., compared with water at 15.5°C. The specific gravity of the distillate between 315°C. and 355°C., shall be not less than 1.08 at 38°C., compared with water 15.5°C.

The specific viscosity at 82°C., when taken in an Engler viscosimeter shall not exceed 1.3. The term specific viscosity shall mean the number of seconds found for the sample tested divided by the number of seconds for water at 20°C., as given in the official certificate for the viscosimeter used.

The oil shall not contain more than 3 per cent. of water. Oil samples taken by the inspector from the treating tank during the progress of the work shall at no time show an accumulation of more than 2 per cent. of foreign matter, such as sawdust and dirt, and due allowance shall be made for all foreign matter, either water or material insoluble in benzol and chloroform, by injecting an additional quantity of oil into the block.

SPECIAL SPECIFICATION FOR HEAVY CREOSOTE OIL

"The oil shall be a distillate obtained wholly from coal tar.

It is required by this specification that the oil used shall be wholly

[1] Proposed by committee American Society of Municipal Improvement, 1916.

a distillate oil obtained only by distillation from coal tar. No other material, of any kind, shall be mixed with it.

The oil shall contain not more than one (1) per cent. of matter insoluble in hot benzol and chloroform.

Its specific gravity at twenty-five (25) degrees C. shall be not less than 1.08 and not more than 1.12.

The oil shall be subject to the standard distillation test and the amount of distillate shall not exceed the following limits in percentage of dry oil:

Up to 150°C., 2 per cent.
Up to 210°C., 10 per cent.
Up to 235°C., 20 per cent.
Up to 315°C., 40 per cent.

There has been much discussion as to the relative merits of the light and heavy oils for the treatment of wood block, and exact data on the subject are lacking. The following facts are apparently well established:

Table 15.—Comparison of Light and Heavy Oils for Wood Block Preservation

Heavy	Light
(*a*) Cheaper than the light oil.	(*a*) More expensive than heavy oil.
(*b*) A little better for waterproofing than the light oil.	(*b*) Has better preservative properties than the heavy oil.
(*c*) Will probably preserve the blocks until they wear out.	(*c*) Bleeds less than the heavy oil.
(*d*) Contributes to bleeding.	(*d*) Not quite as good a waterproofing material as the heavy oil.
(*e*) Does not volatilize readily.	(*e*) Volatilizes more readily than the heavy oil.
(*f*) Contains little material soluble in water.	(*f*) Contains more water soluble portions than the heavy oil.

Some attempts have been made to employ products of water-gas tar and of petroleum for wood preservation, but the use of these materials is, as yet, in the experimental stage, and is not common practice.

Quantity of Preservative.—Experiments have demonstrated that for proper preservation of the blocks it is probably unnecessary to use to exceed 10 lb. of creosote oil per cubic foot of timber, but that for securing the necessary degree of waterproofing at least 16 lb. per cubic foot must be used, and it seems to be established that little benefit is obtained from the use of

more than 16 lb. per cubic foot of timber. Practice in the United States is to treat with quantities varying from 12 to 20 lb. of creosote oil per cubic foot of timber, while in many cases a much less quantity is used for the blocks laid in European cities.

Sometimes when blocks are to be used for streets on which the traffic is very heavy, they are treated by merely dipping in hot tar. The amount of preservative thus absorbed is sufficient to preserve the blocks for the length of time that they can be expected to wear under the traffic conditions.

Bleeding.—Complaints are often made that creosoted block pavements become sticky in warm weather, the tar exuding from the blocks and sticking to the shoes of pedestrians, soiling clothes and being carried into stores and residences, and becoming a general nuisance. The causes of bleeding are several:[1]

1. The use of a tar and creosote mixture containing too much tar. Such an oil does not penetrate the blocks as thoroughly as do the lighter oils and the carbon in the tar has a tendency to lodge in the outer fibers of the block. When the oil in the block warms up and increases in volume the exudation brings with it the carbon. The heavy and sticky mixture of tar and carbon adheres to everything coming into contact with it. For these reasons specifications frequently limit the amount of free carbon in the oil to 1 per cent. In the past as much as 4 per cent. has been permitted.

2. The use of too much oil. If the treatment is in excess of 16 lb. per cubic foot, it is inevitable that some bleeding will occur and treatments of 20 lb. per cubic foot or more are sure to bleed excessively.

3. Improper seasoning and treatment of the blocks. Artificial seasoning and the preliminary and final vacuum are thought to be advisable as reducing the amount of bleeding. The impregnation should be complete—not merely in the outer part of the block.

4. Insufficient provision for expansion of block in the pavement. If the block cannot increase in size when it swells, the effect will be to squeeze out the creosote.

5. The use of a filler soluble in creosote oil. Such a filler will soften up in time and exude at the joints. If too much filler is used, the trouble is aggravated.

The preventive for bleeding then is to use not to exceed a 16-lb.

[1] Weiss, "The Preservation of Structural Timber," p. 201.

treatment, to use pure creosote or creosote in which there is but little carbon-free tar, either to treat green timber or to steam season the timber, and to use a filler not soluble in creosote and to provide ample expansion joints.

The cure for bleeding is to keep the pavement surface covered with torpedo sand until the bleeding stops.

MANUFACTURE OF THE BLOCKS

Cutting of Blocks.—The planks from which the blocks are to be manufactured are sawed with a thickness equal to the width desired in the finished block, which is from 2½ to 4 in. The planks are run through the planer to size them so that all blocks will be of the same width. A plank that is unusually dense, is wet, or is filled with pitch will come through a little thicker than one that is dry or soft, so that some slight variations in thickness of plank and consequently width of block is unavoidable in the process of manufacturing. The planks are inspected and any sections that contain inferior wood are cut out and rejected. The good portions of the planks are cut into lengths varying with the number of saws in the cutting machine used. The cutting machine generally consists of a gang of saws that will cut a number of blocks at one time. From the cutter the blocks are delivered into iron racks in which they are piled loosely. The racks when filled are run into the treating cylinders which are usually about 8 ft. in diameter but of various lengths. Most of the treating cylinders will contain ten or more racks of blocks.

Seasoning and Treating.—When the blocks have been put into the cylinder it is closed tightly and the blocks are steamed to soften the pitch and resinous material. The steaming process to be of the greatest benefit must continue for at least 5 hr., although frequently a shorter period of steaming is specified. After the steaming process, the cylinder is subjected to a vacuum which is intended to draw out from the blocks the moisture and some of the pitch and resinous material. All water that may have come out into the cylinder is pumped off and after the vacuum has continued until the blocks are dry the creosote oil is introduced into the cylinder and pressure applied until the proper quantity of oil has been forced into the blocks. The pressure permitted is generally limited to 200 lb. per square inch and often a less pressure is effective. The pressure must continue

for about 3 hr. to insure thorough impregnation. When the proper impregnation has been secured the excess oil is pumped away and the blocks are allowed to drain for about 30 min. before being removed from the cylinder. It is also recommended that a final vacuum be drawn and held for about 30 min. to dry the blocks, but this practice is not general.

Inspection of Blocks.—The timber is inspected before it is cut into blocks and most of the defective material thus eliminated. The blocks can be weighed before they are placed in the creosoting cylinder and can be weighed again after coming out and thus the quantity of creosote injected can be computed. A slight error exists due to the fact that some moisture is extracted from the blocks during creosoting, but probably this is a small amount. A more reliable way of determining the amount of creosote injected is to observe the gage readings on the tanks before and after the creosoting treatment. Knowing the temperature of the creosote during treatment and in the tanks, the quantity injected can be computed. After the blocks are laid in the pavement they are again inspected and those that are checked or that contain large knots or other defects are removed and turned over or are replaced by good blocks.

CONSTRUCTION OF THE PAVEMENT

Foundation for the Wood-block Pavement.—The principles to be observed in the construction of the concrete base for a wood-block pavement do not differ from those discussed in connection with the brick pavement, and need not be repeated. It may perhaps be said in passing that the thickness of concrete base should never be less than 5 in. and on the heavier-traffic streets should be 6 to 8 in. in thickness. It should be very carefully finished so as to have a smooth surface true to cross-section. This is of great importance with this type of pavement.

Bedding Courses.—Several methods of bedding the blocks are employed of which the most common in the United States is to place a sand cushion on top of the concrete foundation, similar in character to that which is used for the brick pavement and constructed in the same manner. Experience with the sand cushion has not been entirely satisfactory because it has been prone to wash from under the blocks or to shift when dry, allowing the pavement to become uneven. This is particularly

noticeable on streets carrying car lines, the jar of the cars being sufficient to loosen the blocks along the track and afford an opening for water. This has led to the adoption of the mortar cushion which has been described in connection with the brick pavement, and it is much superior to the sand cushion for wood-block pavements. In other instances a thick coating of tar is spread on the concrete foundation and covered lightly with sand and the blocks are laid on the mastic thus produced. When the blocks are laid in this manner the concrete foundation must be finished with the surface as true to shape as that of the finished pavement

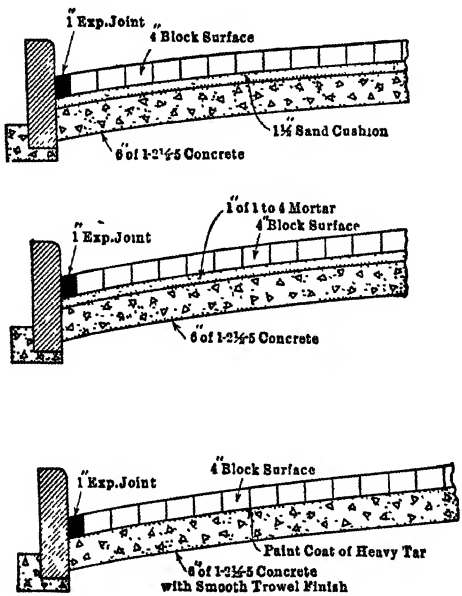


FIG. 58.—Cross-section for wood-block pavement.

and with a troweled mortar surface. This method is used extensively abroad and is coming into use in the United States, and undoubtedly is one of the very best methods for laying this type of pavement. A slight modification of the above method is found where one face of the block is dipped in tar just before it is placed on top of the concrete foundation which has previously been coated with a thin layer of sand. In other instances the concrete foundation is coated with tar and the blocks laid directly thereon.

The blocks are laid in regular rows either at right angles to the curb or an angle of 65° therewith, the latter probably being the

and Quincy Street hot asphalt was spread over the concrete immediately before the blocks were laid. For the remainder of the pavement, north to Adams street, the blocks were placed on the bare concrete and covered with a coat of hot pitch and sand. Blocks of yellow pine were purchased under the standard specifications of the Chicago Board of Local Improvements, which prescribe the use of 12 lb. of creosote oil.

The main reason for the experiment, as given by the city officials, is to find some method which will avoid the shifting of the sand cushion under vibration due to street cars and team traffic. Experience with blocks laid on bare concrete in Europe, as ascertained last summer by L. E. McGann, Commissioner of Public Works, indicated that the method had merit.

Traffic Census

The post-office block was considered an excellent place for an accelerated test of the method as the heavy traffic is augmented by numerous teams which stand along the curb while second class mail is being unloaded. A traffic census as taken by the Citizen's Street Cleaning Bureau between 8 A.M. and 5 P.M. is as follows: Feb. 28, 1907, 2,557 vehicles; Mar. 6, 1911, 3,005 vehicles; Aug. 25, 1912, 3,103 vehicles; Aug. 12, 1913, 2,711 vehicles; Mar. 12, 1914, 2,910 vehicles.

In 1914 the traffic consisted, on a daily average, of 2,050 horse-drawn vehicles, 53 mounted horses, 568 motor cars, 232 motor trucks and 7 motorcycles. During the same period 478 street cars passed the observer. On blocks north and south of the post office the total number of vehicles on Dearborn Street was 2,546 and 2,263, both less than in front of the post office. While the pavement in question did not receive its proper proportion of the passing traffic, the actual wear due to the standing teams undoubtedly compensated to no small extent.

Warped Concrete Surfaces

One of the most difficult parts of the new work was to obtain the proper warped surfaces due to the rise and fall of the gutter elevation between inlets to the level grade at the rail and to the corresponding elevations on the parabolic curves halfway between the rail and curb. Only the west side of the street, 16.6

ft. wide from curb to rail, was paved. On top of the main body of the concrete, 1 by 6-in. dressed boards were secured at the rail and curb and bent over stakes set at the center. These boards were laid flat, 12 ft. apart, and a screed was used to strike off the 1½-in. coat of 1 to 3 mortar. Finishing was done from a bridge with a wood float about 1½ ft. long.

RECENT PRACTICE IN LAYING WOOD BLOCKS[1]

The wood principally used has been long-leaf (yellow) Southern pine, which from experience has been found to give excellent results. Most specifications now, however, admit Norway pine and tamarac and white birch as a result of experimental pavements laid in Minneapolis, which showed the suitability of these woods. No doubt other species of wood make satisfactory pavements, but on account of the incomplete knowledge of their value city engineers, as a rule, prefer a wood that has proved satisfactory.

The blocks are from 3 to 4 in. wide and vary in depth from 3 to 4½ in., with a length of from 5 to 10 in. As for all timber specifications, the blocks should be sound, free from large or loose knots, shakes, wormholes and other similar defects. As to the proportion of sap and heartwood, the present specifications are not very rigid, as experience has shown that treated blocks having both sapwood and heartwood do not vary in their wearing qualities.

The preservative used is a creosote oil having a specific gravity of from 1.08 to 1.14, containing a percentage of tar, free from carbon. Coal-tar oils are used in preference to water-gas creosote, as sufficient experiments have not yet been carried out with the water-gas creosote to determine its relative value.

The writer has been corresponding with a number of city engineers with a view of obtaining opinion as to the most satisfactory amount of treatment required per cubic foot of block, according to the experience of each city, and in replies from twenty cities in the United States has ascertained that six of these cities use 16 lb., two of them 18 lb., and twelve of them 20 lb., spending to some extent on local conditions.

Laying the Pavement.—The base for wood-block pavements should be of concrete, from 5 to 6 in. deep, having the crown

[1] Andrew F. Macallum, City Engineer, Hamilton, Ontario. Read at Canadian and International Good Roads Convention, Toronto.

parallel to the finished crown on the blocks. An uneven or irregular base is detrimental to any pavement, as it is liable to cause a depression in the surface to hold water, which the repeated impacts of wagon wheels is certain to increase, giving an uneven surface. Upon this concrete base is placed either a sand or mortar cushion. This cushion is usually 1 in. deep, and has its surface struck by templates to a surface parallel to the contour of the finished pavement. Where sand is used, the sand is such that it will all pass through a ¼-in. screen, besides being clean. If a mortar cushion be used, some engineers use a proportion of 1 of cement to 3 of clean sand, to which sufficient water is added to insure the proper setting of the cement. Other engineers obtain good results by mixing and placing the cement and sand dry. This custom is simply a means of securing a uniform surface for the blocks to rest upon and distribute the load. Alongside or between street car tracks, however, or on grades, sand cushions are apt to become uneven or flow, caused by the vibration of the rails, or by water getting in alongside the rails, so that under these circumstances a concrete cushion should be used. Away from the car tracks the question of whether a sand or mortar cushion should be used is a matter of opinion. Sand gives a better cushioning effect and the blocks do not have to be rolled so soon after laying as when a mortar cushion is used.

English and French practice does away with this cushion altogether, but the concrete base is finished off as smooth as a concrete sidewalk and to the exact contour of the surface of the pavement. This extra care and workmanship obtain results that are excellent, inasmuch as the finished surface of the blocks has no depression, and consequently the wheels cause no impacts.

In most cities it is not possible to lay the blocks shortly after coming out of the treating plant, and the hot sun and wind during shipment and before laying is apt to check the blocks and cause oil to exude. The blocks should be piled closely when delivered on the street and sprinkled before laying.

Generally, the blocks are laid at right angles with the curbs, with an expansion joint at each curb of from ¾ to 1½ in., according to the width of the pavement. Alongside the curbs three rows of block are laid parallel to the curbs, with the expansion joint next to the curb. Placing a longitudinal row of blocks, with an expansion joint on each side is sometimes done,

but is not good practice, as the single row of blocks between the joints will almost certainly rise up about the level of the adjoining pavement as the joints close up. Cross expansion joints have been used also by the writer when the treated block used had been piled on a street for several months, but for fresh blocks, properly treated, they are not necessary on streets of heavy traffic. On streets of light traffic, however, there should be cross expansion joints, placed from 30 to 50 ft. apart and having a width of about 3/4 in. It is hardly necessary to say that the blocks should be laid with the grain vertical and having the joints in adjacent rows broken by a lap of about 2 in. The blocks should be laid neither too loose nor too tight, so that a block can be raised without disturbing the surrounding blocks, or 1/8 in. apart. After the pavement is laid it should be rolled thoroughly with a roller varying from 3 to 5 tons until a perfect surface has been secured, with no depressions and the blocks firmly in place. There should be no difficulty in this, as the usual specifications for blocks allow of a variation of but 1/16 in. in depth, so that if the foundation and cushion have been properly laid there is usually very little trouble about depth of the blocks.

Alongside street railway tracks and about manholes special care should be taken in laying the blocks. It is usual in such cases to thicken the cushion so that the blocks shall be about 1/4 in. above the wearing surface of the rail or cover, and in a very short time the traffic will rub these blocks down to the level of the rail. Alongside rails, to prevent water flowing down and under the blocks, two methods are used: One is to place a specially cut creosoted plank under the rail to give a vertical surface against which the blocks are paved; and the second and usual method is to plaster the web with a rich mixture of sand and cement to the width of the rail-head, and the blocks are then laid against this. As with other pavements it has been found that the girder lip-rail is more satisfactory than the ordinary tee-rail, unfortunately in use in most towns, for the permanence of the block on the inside or gage side of the rail. Incidentally, it may be said that no pavement will be satisfactory alongside a street railway track if the rails lack sufficient weight, stiffness and foundation to prevent movement, especially at the joints.

There is diversity of opinion among engineers as to the best joint filler to be used. The American Society of Municipal

Improvements recommends a suitable bituminous filler when the blocks are laid upon a sand cushion and a sand filler when laid on a mortar cushion. It is claimed for the bituminous filler, which fills the joints between the blocks two-thirds their depth (the remaining depth filled with sand), that it makes an absolutely waterproof pavement, and that it eliminates all expansion difficulties, as each block is surrounded with an individual expansion joint. Unless the filler is a suitable asphaltic cement, with a high melting point and low penetration, there is apt to be a sticky surplus left on the surface. This filler will cost about 15 cts. a square yard more than a sand filler.

A cement grout filler has been used, but unless the traffic can be kept off the pavement for at least 10 days it is little superior to a sand filler.

The sand filler is generally used on streets of heavy traffic, the sand being coarse and sharp-grained, and preferably heated before placing. The writer has used with excellent results a bituminous filler between and 1 ft. outside of street railway tracks and a sand filler for streets. From results obtained he does not consider the extra expense in using bituminous filler justified for such streets unless the traffic be very light. On bridge floors it is better practice to use a bituminous filler with the blocks. After the pavement is rolled, sand to the depth of about ½ in. is spread over the surface and the street is thrown open to traffic.

This method of construction is satisfactory up to a 3 per cent. grade, beyond which the blocks are laid in a different manner. The crown should be as light as possible, being just sufficient to shed the water freely, which applies also to the pavements between street railway tracks.

When the grade of the street exceeds 3 per cent., a creosoted lath is inserted between each cross-row of blocks to leave a space of about ⅜ in. The lath fills this space practically for two-thirds of the depth of the block and a bituminous filler is used. This method of laying the blocks forms a good foothold for horses, and is satisfactory up to and including a 6 per cent. grade.

One of the criticisms made of treated wood-block pavements is that it is slippery, but in the writer's experience he has found that there is very little difference between these blocks and sheet-asphalt pavements. When covered with a light frost or snow,

or when the weather is foggy and damp, the pavement may become objectionably slippery.

In traffic observations made at Philadelphia, New York and other cities, the evidence shown by the engineer at these places indicated that where treated wooden block and granite blocks were on parallel streets, 70 per cent. of the teaming went on the wooden blocks.

On Stuart Street, in the city of Hamilton, the writer laid treated wooden blocks between the street car rails and granite block between the outside rails and curbs, the pavement being on a 5 per cent. grade. Although most of the traffic was of a heavy teaming nature, it was found that fully 80 per cent. of the traffic, except on wet days, was on the wooden block.

The first cost of wood-block pavement is undoubtedly higher than that of most of the other paving materials, averaging in the city of Hamilton from $2.85 to $3 per square yard, exclusive of grading. When its cheapness of maintenance, ease of cleaning, low tractive resistance and durability are taken into consideration, this pavement, with its relatively high first cost, will compare favorably and prove ultimately cheaper than one lower in first cost.

CEMENT-SAND BED BEST FOR WOOD-BLOCK PAVING[1]

Portland cement should be mixed with the sand used as a bedding course in the laying of creosoted wood-block paving for the following reasons:

1. Along streets with car lines, the rise and fall of the rail and the jar of passing cars will cause the shifting of a plain sand cushion. Where water gets in around the rail this rise and fall seems to have a pumping action, forcing the water and sand considerable distances.

2. When service cuts are made a dry, loose sand cushion may run for some distance, especially on a grade, due to the blows of cutting the foundation. This displacement of the cushion may be slight, and pass unnoticed when the cut is repaved. Any settlement of a portion of blocks causes unnecessary wear.

3. When any bulging of the blocks or other accident occurs which makes necessary the relaying of a portion of the blocks,

[1] Clark R. Mandigo, Assistant City Engineer, Kansas City, in *Engineering Record*, May 22, 1915.

the work is more easily and accurately done where the bed for the blocks retains its original position and is smooth and hard.

4. A cement-sand bed is good insurance against the displacement of the surface due to water getting underneath the blocks on a grade and shifting a loose sand course. This would apply to springs and leaky service pipes or mains as well as storm water.

5. Wood blocks are usually laid with as true and even grade and crown as it is possible to get. If the surface is kept true there is practically no wear on the blocks.

The term "cushion" where cement is used, is, of course, a misnomer. It should be called leveling course or laying bed. The blocks themselves are a cushion. Probably the best way to lay wood blocks is in asphaltic cement mopped on an absolutely smooth floated concrete foundation. Such a base, however, is very difficult to obtain in the present state of municipal contracting and a cement-sand bedding course accomplishes very nearly the same results except for the waterproofing of the under side of the blocks.

BEDDING THE BLOCKS

The cement and sand should be mixed dry in the proportions of about 1 to 4, spread on the foundation, templated and the blocks set and rolled in the same manner as where a plain sand cushion is used. This allows the blocks to be properly bedded before the cement has set and avoids any difficulty in placing them on a wet mortar. After the blocks are rolled, the water necessary for the cement can be added by sprinkling the surface of the pavement, or enough moisture would probably be absorbed from the concrete foundation to set the cement. The bedding course should be only thick enough to level up the unevenness in the base, and with ordinary care in laying the concrete foundation, ½ in. should be sufficient. The increase in cost of such a cement-sand course over plain sand is so slight, while the advantages gained are so important to the wearing surface, that continuing the use of plain sand as a bed for wood-block paving appears to be poor economy.

CHAPTER XII

STONE-BLOCK PAVEMENTS

The stone-block pavement is one of the oldest types of pavement and one that has been very widely used in Europe and America, especially for streets of heavy traffic. For dock and warehouse districts, and for streets subjected to very heavy loads, it is the only type of surface having the requisite durability. The earlier pavements of this type often became rough and noisy, but better methods of construction have been gradually developed until those constructed in recent years are high-class surfaces of great durability.

Kinds of Stone Used for Paving Blocks.—By far the larger proportion of the pavements of this type have been constructed with granite blocks. For this purpose several varieties of granite of varying degrees of hardness are employed. Trap blocks have been employed to some extent, but in recent years the granite block has largely superseded the trap block.

Sandstone block have been used to a considerable extent, where suitable material is available and where traffic conditions require that the pavement shall be as free from slipperiness as possible, and at the same time be one adapted to heavy loads. Quartzite blocks have been used to a limited extent.

Requirements for Paving Blocks.—A stone block that is to be used for a pavement will be subjected to impact and abrasion just as any kind of pavement block is, but since stone blocks are laid on streets carrying the heaviest kind of traffic, the abrasion is particularly severe. The stone must be dense and hard and fairly tough. It also is desirable that it wear without a polish and therefore with a slightly granular surface so that excessive slipperiness may be avoided. Any stone will likely wear down to a smooth surface but some kinds of stone are more apt to become slippery than others.

Size of Blocks.—The length of the block cannot be too great or it will not fit closely to the curved section of the pavement or

it will tip under the action of the traffic. The block must not be too short or it will have insufficient bearing to support the loads. Specifications are by no means uniform in the length requirements but if the blocks are not less than 6 in. long nor greater than 12 in. long they will be well within the usual requirements. Blocks of various lengths are used on the same street, being mixed indiscriminately and laid as they happen to come so long as joints are broken properly.

The width of the block is to be such as will insure good foothold. If the block is too wide the cross-joints that give a foothold for horses will be too far apart and the horses will slip badly. If the blocks are too narrow there will be excessive wear on account of the large number of cross-joints, and, moreover, the blocks are likely to be unstable in the pavement if they do not have enough width to give good bearing. Generally speaking, the blocks are seldom made less than 3½ in. wide or more than 6 in. wide, but all blocks used on any job should be of the same width. This is to insure uniformity of the courses and even width of cross-joints.

Thickness and Depth of Block.—Early pavements were laid with blocks 6 or 8 in. deep because it was desired to secure stability to the surface. Obviously the blocks could not wear out by grinding down until the pavement was too thin to support traffic. Long before that was possible the pavement would be too uneven for service. More recent practice is to put a good foundation under the blocks and to reduce the thickness of the wearing surface to 5 in. or, in exceptional cases, 6 or 7 in. American practice is like European practice in that deep blocks have been used quite generally in the past.

Special Kinds of Blocks.—In addition to the blocks already described, which may be considered the standard type of stone paving block, some special blocks have been tried out in Europe in recent years and may be introduced into the United States.

Grooved Blocks.—For pavements on steep grades, blocks having a groove along the middle are used for the purpose of giving better foothold for horses. The groove is usually about ¾ in. wide and ½ in. deep. The blocks are generally 6 in. wide so that there is a transverse groove every 6 in., alternating with the cross-joints which are also 6 in. apart.

Stone Cubes.—Cubes 4 or 6 in. in size are used to some extent. Commonly they are laid with the edges diagonally across the

street, but occasionally they are laid in transverse rows with transverse joints. The cubes used in some German pavements are about $2\frac{1}{2}$ in. in size, and for the Durax pavement about $3\frac{1}{2}$-in. cubes are used.

Uniformity of Paving Blocks.—Since stone paving blocks are handmade, the degree of uniformity secured depends upon the price that the municipality is willing to pay for them. The stones used have well-defined planes of cleavage so that skilled workmen can produce blocks of any desired degree of uniformity if they are paid sufficiently for it. In specifying the permissible variation it should be borne in mind that nothing is gained by severe requirements in this direction. For strictly high-class pavements it is desirable to require that the variation from the specified width shall not exceed $\frac{1}{4}$ in., and in depth not to exceed $\frac{1}{4}$ or $\frac{3}{8}$ in. The faces of the block should be free from bulges or depressions exceeding about $\frac{1}{4}$ in. It is also customary to require that not more than one block per square yard shall show a drill hole on the side, and that no drill holes shall show at the ends. The sides of the block must be smooth enough to insure room for the filler, and the upper face should be as nearly a plane as practicable to make it. The edges to the upper face should be practically straight lines, and the faces should be perpendicular to each other at the top. It is permissible, however, for the block to be slightly smaller on the bottom than on the top, *i.e.*, a truncated pyramid, but the difference in width at the bottom and top should not be greater than 1 in.

For second-rate paving a greater variation in the various dimensions is permissible, but otherwise the blocks are of the same general shape and size as for first-class pavements.

Requirement for Blocks.—To sum up, the stone block should be made from a fairly tough stone having a crushing strength of at least 16,000 lb. per square inch. If made of granite the stone should be of fairly uniform composition, the constituent minerals being well distributed and free from an excess of mica. No block that shows signs of disintegration or that is cracked, chipped or irregular in shape, may be used. The dimensions must comply with those specified within $\frac{1}{4}$ in., and the faces must be substantially plane and free from bunches or depressions. The following table shows the variations in the several dimensions permitted by American cities:

TABLE 16.—ALLOWABLE VARIATION IN DIMENSIONS OF STONE PAVING BLOCKS

	Length	Width	Depth	Width of joint
Minimum....	6 in.	$3\frac{1}{2}$ in.	4 in.	$\frac{1}{4}$ in.
Maximum	10 in.	6 in.	8 in.	$\frac{1}{2}$ in.
Average specification.	.	4 in.	5 in.	$\frac{3}{8}$ in.

Foundations for Stone-block Pavements.—Like many other kinds of paving surface, the stone block has in the past been laid on various sorts of foundation such as concrete, macadam, Telford, old cobblestones and sand or gravel. Modern practice has settled down to the almost universal use of Portland cement concrete for a base. Sometimes old gravel or macadam foundations are utilized, and a few cities still permit the construction of a base of those materials. It is obvious that a pavement of this class requires a very stable foundation if it is to remain free

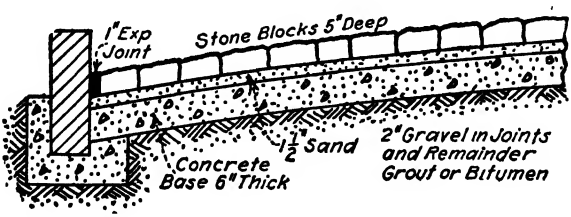


FIG. 59.—Cross-section for granite-block pavement.

from depressions and unevenness due to the settlement of individual blocks. It is also apparent that if the traffic requires as durable a surface as a granite block, it will be heavy enough to require a very substantial foundation to support the surface. The concrete foundation is constructed of the materials and in the manner that has already been discussed. The thickness is rarely less than 6 in. and is often made 8 in.

Sand Cushion.—Since there is likely to be a variation of $\frac{1}{2}$ in. in the depth of adjacent blocks in a course, the sand cushion must be thick enough to permit adjusting the blocks so as to have a uniform surface. Generally the layer of sand is spread and shaped to a thickness of 2 or 3 in. As in other types of pavement that have been placed on a sand layer, some dissatisfaction is felt with the use of the sand layer because of its tendency to shift under the blocks. The sand used need be only a fairly

clean sand composed of good hard particles and graded from about ¼ in. down.

Mortar Cushion.—Instead of the layer of sand for bedding the blocks, the lean mortar bed is coming into use, and has much to recommend it. The mortar is mixed dry in the proportions of 1 part cement to 3 parts or 4 parts of sand, and spread to the proper thickness. After the blocks have been placed, the surface is sprinkled to give water to hydrate the cement in the mortar bed.

Whether the sand layer or a mortar layer is used, it should be spread, rolled and struck off to the proper thickness in the manner described for the brick pavement.

Laying the Blocks.—The block layer uses a hammer with a curved metal blade at one end. With the blade he scoops out a depression in the bedding course and places the block so that the top conforms to the finished surface and taps the block gently to place. If the blocks are quite uniform in depth he may be able to bed them by means of the hammer without scooping out the sand. Special care is taken to have the joints as close and uniform as possible.

The courses are generally laid perpendicular to the curbs, except at street intersections where they are laid parallel to the four diagonals of the intersection. In a few instances stone-block pavements have been laid with the courses diagonally across the street, but where so laid they do not wear as well nor furnish as good footing as when laid perpendicular to the curbs, and the method has not been used extensively.

Tamping.—After the blocks have been placed they are rammed to place with a heavy tamper, a part of the work that must be carefully and thoroughly done. If low places develop under the ramming, the block so affected should be removed, sand added to the bed and the blocks replaced and again tamped. The blocks are inspected before the ramming begins, and all defective blocks removed and replaced with good ones. After the ramming, any blocks that have spalled or split are replaced. The surface when thoroughly tamped is ready for the filler.

Some idea of the importance of proper ramming may be obtained from the fact that it requires one man ramming for every three setters, and it would be better if there were one rammer for every two setters. The object of ramming is not merely to produce a uniform cross-slope, but to thoroughly bed each block so that it will not settle under traffic. If in bedding the block

it is driven below grade, it is raised, the requisite amount added to the bedding course and the block replaced and again rammed. Some engineers believe it to be desirable to sweep enough gravel of pea size into the joints to fill them about 2 in. before ramming. This serves to hold the blocks more securely in place until the filler has been applied

Sand Filler.—Where stone blocks have been laid on a sand or gravel foundation, it has usually been customary to fill the joints with sand or pea gravel and sand mixed. The filler material is spread dry on the pavement and swept into the joints, an excess being left to be worked into the joints under traffic. For pavements that are to be made waterproof, the pitch fillers and cement grout are used.

Fig. 60.—Crossing stones in stone-block pavement.

Pitch Fillers.—When a pitch filler is used, the grade commonly specified for brick-block pavements is employed. Sometimes the joint is partly filled with pea gravel before the filler is poured and sometimes no gravel is used. The pitch is applied at a temperature that will insure complete penetration and the joint is filled flush with the surface and then sanded. English practice is to use for a pitch filler a mixture of tar pitch and creosote oil in the proportions of about 1 part of the creosote oil to 10 parts of pitch. In many instances English practice is to fill the joints partially with pea gravel before the pitch is poured.

Asphaltic Fillers.—Asphaltic fillers have been used on stone-block pavements to only a limited extent on account of the difficulty in securing adhesion to the blocks. When adopted it is applied just as the pitch filler would be.

Cement-grout Filler.—This type of filler is being adopted more and more for the stone-block pavement. As for other types of fillers, the joint is frequently partly filled with pea gravel before the grout is poured. The grout filler is mixed and applied in exactly the same manner as the grout filler for the brick-block pavement.

Recut Granite Blocks.—Many of the earlier block pavements were laid with blocks 6 and 8 in. deep. These have worn until the pavement is exceedingly rough and uneven. A few cities have tried taking up these blocks and cutting off the rounded

Fig. 61.—Old style open-joint block pavement.

part of the head and relaying them, as they are still of sufficient depth to give long service.

Generally the old blocks are taken up and re-dressed and piled along the sidewalk until the new base course and cushion have been laid, and are then placed exactly as new blocks would be.

Crossing Stones.—In order to contribute to the comfort of pedestrians, crossing stones are often provided in stone-block pavements. These consist of two or more rows of slabs at the crossings. The slabs are usually 18 in. wide and from 4 to 6 ft. long, and are placed with two or three rows of ordinary paving blocks between them. The slabs are about 5 in. thick and are

laid on the sand bed with the top conforming to the surface of the pavement. Granite is generally used if the paving is granite, although trap is sometimes substituted. On streets paved with the sandstone blocks, the crossing stones are also of sandstone.

Characteristics of the Stone-block Pavement.—The granite-block pavement possesses characteristics adapted to the severest traffic conditions, and is generally laid only where it is necessary to provide something that will withstand the hardest kind of wear. It will have long life under such conditions if it has been properly laid. It has a tendency to become slippery, especially if the harder granites have been used, and the tops of the indi-

Courtesy Mr. Zenas Carter.

FIG. 62.—Granite-block pavement with close joints. Age 15 years.

vidual stone will wear off rounding unless a good filler is provided. Grout-filled block pavements are more slippery than the pitch-filled. In any case a granite-block pavement is apt to be noisy and somewhat rough. It is not an easy pavement to keep clean, nor is its appearance as pleasing as that of many types, but, as before noted, it is built where a very durable pavement is essential.

The trap-block pavement has all of the characteristics of the granite-block pavement except that it is more slippery after traffic has worn the blocks to a polish.

The sandstone-block pavement is not adapted to such severe traffic conditions as those to which the granite and trap blocks may be subjected, without undue wear. The sandstone-block pavement is less noisy than the other stone-block pavements, and much less slippery. It has most of the other characteristics of the granite-block pavement.

EXAMPLES OF GOOD PRACTICE

NEW YORK CITY[1]

The highway officials of New York City consider that for streets with any considerable amount of city traffic, the most satisfactory pavements are granite block, wood block and sheet asphalt. A considerable part of the latest report of the Bureau of Highways is given to the discussion of stone block, and from this we abstract the following:

Granite block, even under the best conditions, is noisier under steel tires and horse-drawn vehicles than others. It is not so easy to clean. With tar-filled joints a cut can be restored practically as good as the original pavement. Its slightly roughened surface gives a good foothold for horses' hoofs, and its durability is superior to all other types.

The popular idea of granite pavement in this country is based on the old block pavements laid with wide joints, where the head speedily became rounded, producing a cobblestone effect. As laid under the present specifications, with flat heads and close joints, it presents a nearly smooth surface and one which cannot wear rounded and uneven. Very hard granite is liable to wear as smooth and slippery as any other type.

It is now universally admitted that granite block for pavement should be accurately cut to standard dimensions and laid with close joints. There are, however, two distinct points of view in regard to the physical composition of the blocks used. That taken by Mayor Gaynor's committee on pavements is to the effect that all deterioration in stone pavement is due to wear consequent on lack of sufficient crushing strength and hardness, and that only the hardest granites can stand the wear of traffic under present conditions.

The other point of view is exemplified in the following statement of Mr. McClure, city engineer of Worcester, Mass., which is of interest, as that city has made extensive use of granite for paving purposes and its streets are admittedly in excellent condition:

"I attribute much of our success in the use of granite blocks to the fact that we have always used the New Hampshire granite, the greater part of the blocks coming from the Marlboro quarries,

[1] *Engineering Record*, Jan. 3, 1914.

which is soft enough to wear without polish and hence with a slight degree of slipperiness."

Rounded blocks are not an evidence of lack of hardness, but rather the contrary. Many of the older pavements where the blocks are in the poorest condition, with rounded tops and extremely polished surfaces, are known to have been laid with hard material, the constant friction of horses' hoofs and steel tires on the edges of the blocks, combined with the wide sand joints, producing the above results. Under similar conditions a soft block would wear on the top as well as on the edges, as can be observed in the Medina sandstone pavements of Rochester and Buffalo.

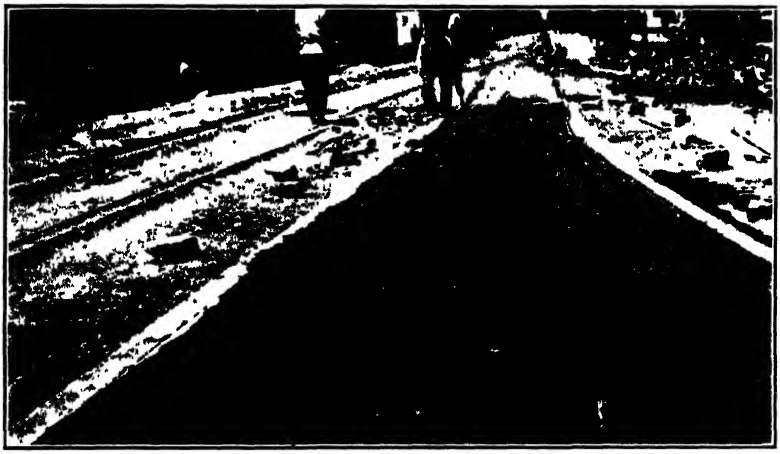


Fig. 63.—Granite-block toothing course along car track.

The Fourth Avenue pavement was practically the first laid under the improved specifications. With the exception of certain portions where faulty work was done or where operations of the Department of Water Supply, Gas and Electricity and the gas company have injured it, and excepting, also, the railroad area including between limits 2 ft. outside of the tracks where the pavement has not yet been relaid, and where, due to the poor condition of the rails it has settled in many places, the surface is good, and the blocks show little evidence of wearing round after two seasons of service. Work is shortly to be started in the railroad area, which is to be entirely repaved with new blocks after the rails have been changed.

The following table contains the names and locations of the principal granite quarries available at present for New York paving blocks, and indicates approximately the present capacity of each:

TABLE 17.—NAMES AND LOCATIONS OF GRANITE QUARRIES AVAILABLE FOR NEW YORK

Quarry	Capacity in blocks per year
Salisbury, N. C., Harris Granite Quarries Co....	3,000,000
Rockport, Mass., Rockport Granite Co..........	6,000,000
Westerly, R. I., Booth Bros..	500,000
Alexandria Bay, N. Y., J. Leopold.............	500,000
Long Cove, Me., Booth Bros.	2,500,000
Roberts' Harbor, Vinal Haven, Me., Booth Bros.	1,000,000
East Boston, Vinal Haven, Me., J. Leopold	1,500,000
New England Granite Co., H. H. Mass and Vt.	6,000,000
Mt. Waldo and Mosquito Mountain, Me., John Pierce	2,500,000
Mt. Airy N. C	500,000

The quarries are arranged approximately according to the hardness of their output. Salisbury, Rockport, Westerly and Alexandria Bay are extremely hard. The Rockport stone has a coarse grain, rendering it very difficult to obtain a finely dressed block.

The Borough of Manhattan alone is at present requiring annually between 200,000 and 300,000 sq. yd. of granite block, or from 6,000,000 to 9,000,000 blocks.

RE-DRESSED GRANITE BLOCKS IN NEW YORK CITY[1]

For repaving purposes existing granite blocks, originally laid on a sand foundation, have an economic value. In 1908 the suggestion was made to the authorities of the Borough of The Bronx, New York City, as to the advisability of making use of the old granite blocks by splitting and re-dressing them. Strange to say, the person to make this suggestion was a paving contractor, largely interested in granite quarries. The scheme met with approval and a contract was awarded for repaving Webster Avenue from 165th Street to 171st Street, with the result that an excellent pavement was obtained at very low cost. There has been practically no maintenance cost since the contract was com-

[1] R. H. Gillespie in *Proceedings American Road Builders Association*, 1913.

pleted, and the pavement at the present time is in very satisfactory condition.

The blocks laid on sand, under the old specifications, are in most cases fully up to the length specified; in fact, a considerable proportion run from 12 to 14 in. in length and are rarely less than 7 in. in depth. The splitting and dressing consists in breaking in two, blocks 11 in. or more in length, using the broken face as the head and dressing the ends and sides for ½-in. joints. The finished blocks are from 6½ to 8 in. long, 3½ to 4½ in. wide, and 5½ to 6½ in. deep. Blocks shorter than 11 in. are reheaded where necessary, dressed to lay the required joints, and as a rule are used along the street railway tracks. The splitting and dressing are done on the street by cutters who receive about 1½ cts. for each re-dressed block. Each produces from 450 to 600 blocks per 8-hr. day, depending partly on his skill and speed and partly on the character of the granite and condition of the blocks. As the blocks are dressed they are piled along the sidewalk until the concrete is in readiness for the pavement.

The blocks are laid in the usual manner, in rows, at right angles to the curb line on a 6-in., 1-3-6 concrete foundation with a 1¼-in. sand cushion. Up to Nov. 15, 1913, 207,150 sq. yd. (or 7.96 miles) of this type of pavement has been laid in the Borough of The Bronx, all of it with vertical joints filled with Portland cement grout, at an average cost of $1.21 per square yard, exclusive of concrete base, as compared with an average cost of $3.20 per square yard for new improved granite block exclusive of foundation.

During the past 4 years all the improved and re-dressed granite pavements in The Bronx have been laid with joints filled with Portland cement grout, while in Manhattan and the other boroughs they have been filled for the most part with paving cement or paving cement and gravel. Under like conditions a well-grouted granite pavement will give better results than one where paving cement and gravel are used. The grouted pavement is more easily cleaned, is apt to shed water more readily, is slightly smoother, and there is less tendency for the blocks to "turtle-back." There is one temporary but serious objection, while it lasts, to the grouted pavements—interference and inconvenience to business interests along the line of the street due to the time that the street must be kept from traffic while awaiting the setting of the grout. This time should be, under the most favorable

conditions, not less than one week. Still it is quite practicable to pave one-half of a street at a time, and thus to some extent minimize this objection.

For streets which are called upon to accommodate a large amount of heavy commercial traffic, the pavement of the granite-block type (whether new or re-dressed, grouted or tarred) under the present specifications will prove economical and generally satisfactory.

RECUT GRANITE-BLOCK PAVEMENTS IN BALTIMORE[1]

A large area of granite-block pavement, laid in accordance with the old specifications on streets for whose traffic modern paving science would presumably provide totally different surfaces, is Baltimore's heritage from a period when stone surfaces were thought ideal for all purposes. How to replace these pavements with more suitable ones without going to a considerable expense was the problem facing the Municipal Paving Commission when it was created in 1911. About that time, however, the economic value of the old block for repaving purposes was being investigated by the highway engineers of the Borough of The Bronx, New York City, who seem to have been the first extensively to re-dress the blocks and make a new surface of them. This practice was adopted by the Baltimore Commission, but only during the last 2 years have extensive areas been laid. The expense of removing, dressing and relaying the block has been less than two-thirds the prevailing price for new granite block surface.

The old stones were of the usual heavy type, many as large as 14 in. in length, 6 in. in width and 8 in. in depth. The broken blocks are from 4½ in. to 6 in. deep, and those which are less than 3 in. in either surface dimension are not used.

As much of the old block was laid on streets bearing a light traffic only, little trouble is experienced because of the operations of the working gangs. From the old pavements the blocks, which are sand-filled, are removed with crowbars and placed convenient to the cutters, who work in the street, producing about 225 of the small blocks per 8-hr. day. The price for re-dressing is about 2½ cts. per block, although as the work has been let in many contracts this price varied somewhat. The renovated

[1] *Engineering Record,* Nov. 14, 1914.

blocks are carried to the heavy-traffic streets on which they are to be used. They are then laid in transverse courses on a 6-in., 1-3½-7 concrete foundation with a 2-in. sand cushion. The joints are grouted with a 1 to 1 mortar, a thin coat of which is finally applied to the surface. Traffic is kept off the completed pavement for 14 days.

During 1913 there were laid of this new paving about 5,000 sq. yd., and in 1914, to Nov. 1, 3,900 sq. yd. Approximate costs per square yard of finished pavement for this surface are as follows: Breaking up old pavements, $0.09; recutting, $1.00; hauling, laying and grouting, $0.71; total unit cost, $1.80. As the old blocks have practically no value unless used in this way, the cost of laying the recut prisms, exclusive of foundation, may be compared with that for improved granite block, exclusive of foundation. As an average figure for the latter in Baltimore is $2.80, recutting means a saving of 36 per cent.

There still exist in the city about 750,000 sq. yd. of the old granite-block pavement, and it is planned to make similar use of this as opportunity offers. The work is being done under the direction of the assistant engineers of the Municipal Paving Commission, of which R. Keith Compton is chairman.

IMPROVED GRANITE-BLOCK PAVEMENTS[1]

To secure a smooth, even surface—so perfect, in fact, that no crosswalks or bridgestones are used or needed—it is necessary that the citizen require and the engineer specify a carefully made granite block having no projections on the surface exceeding ⅜-in. from an even plane, and that the blocks be laid in the street on a properly drained subfoundation, a substantial concrete foundation, and with close, even joints, and that these joints be filled with a bituminous filler of asphalt or pitch, or grouted with a cement grout consisting of 1 part cement and 1 part sand.

Bituminous vs. Cement Fillers.—The use of the two different types of fillers is largely a question of the likelihood of future openings being made in the pavement. If frequent openings are apt to be necessary, the bituminous filler is more convenient, and where traffic conditions demand quick repair it is preferable. Where openings are not apt to be frequent or where traffic con-

[1] Mr. Zenas Carter in "The American City Pamphlets," No. 143.

ditions would allow blocking off for a reasonable period for the cement grout to set properly, the cement grout filler should be used and will give better results usually than the bituminous filler.

Size of Blocks and Joints.—The next feature of importance is to specify and secure blocks which permit laying with even, close joints; joints for bituminous-filler pavements not to exceed $3/8$ in. and for cement-grout filler pavements not to exceed $1/2$ in. When blocks are laid with wider joints than $3/8$ in. for bituminous-filler work, the blocks will begin to "turtle" or round on all the edges within a few years, on account of the steel shoes of horses tending to chip and break off small pieces every time the calk slips into the joint. With the close, even joint, properly filled, the horses can secure good footholds when handling heavy loads, and the edges are so close together that both blocks on the sides of the joint are forced to take the strain and blow, and neither block is broken or chipped.

A slightly wider joint may be used for cement-grout filler work, as the filler must penetrate well down to the bottom of the block and thoroughly bond the blocks into a monolith form.

Granite blocks vary in size in different locations, and no specific size can be given preference; but it is important to see that all blocks in any single course across the street or area being paved are of the same width; as the use of a $4\frac{1}{2}$-in. block in the course with a $3\frac{3}{4}$-in. block will leave a chance for the narrow block to become loosened, and this gives a chance for the next and the next blocks to move. As a result, an opening in the joint develops and water seeps through to the concrete and shifts the cushion below or upheaves the blocks in the area through freezing in the winter. Of course, with the grout filler the danger is not so great, but it exists.

Granite blocks should not vary more than $1/2$ in. in depth in any case. Much of the old-time unevenness of surface came about through carelessness on this point.

Variations in length are not important, with the exception that blocks over 12 in. in length should not be used, and the variation in lengths should be sufficient to always allow for breaking the joints at least 3 in. so that ruts cannot develop from two end joints being continuous.

Laying the Blocks.—When laying blocks, great care must be used to see that the sand cushion or mortar cushion over the bed

of the concrete is not deeper than necessary. A cushion of 3/4 in. to 1 in. is ample, and the frequent practice of using a cushion of 1 1/2 in. to 2 in. should be abandoned. Before the specifications for improved granite blocks developed there was some excuse for this practice, as the blocks frequently varied 1 in. or more in depth; but engineers now know that this extra depth of block and sand cushion were the cause of much unevenness of surface.

After the blocks are laid in proper courses, they must be thoroughly rammed. All low blocks should be lifted and rebedded and retamped until the entire surface of the pavement is both even and firm. It is best to specify one rammersman to two pavers to insure that every block is rammed to a firm bed. The main trouble from poor ramming is that the poorly bedded blocks will go down under traffic and the surface of the pavement will soon be very uneven; while, on the other hand properly laid granite block pavements have given service for periods of 20 years and more without a single block showing appreciable wear, or any unevenness of surface developing.

CHAPTER XIII

BITUMINOUS ROAD AND PAVEMENT MATERIALS

Asphalt.—The term "asphalt" was until very recent years applied to certain deposits or exudations of black or brownish mineral matter that were found in many places on the earth's surface. These materials were in some instances intimately mixed with finely divided rock and in others were simply masses of a solid or a very viscous liquid in crevices in the earth. All of the deposits had the common property of melting on the application of heat, and of possessing sufficient stickiness when hot to render them valuable as cementing agents. Only within a comparatively few years has the term been applied to various similar materials resulting from manufacturing processes. The asphalts were all more or less soluble in chloroform, benzole and carbon disulphide, and the soluble portion was called bitumen. For commercial reasons the many miscellaneous compounds that resemble those originally designated as asphalts have been exploited as asphalts and the term is, therefore, no longer of significance technically, but is a commercial designation for a large group of generally dissimilar materials having a few similar characteristics. The word asphalt as now used has no more exact meaning than does the word paint. The same is true of the word bitumen which has been used to include not only the soluble portions of commercial asphalts, but also the portion of tar that is soluble in carbon disulphide.

The road builder, therefore, encounters a chaotic and irrational system of nomenclature and definition when he takes up the study of the many kinds of binders that are known commercially as bituminous materials. When cleared of the encumbrances of a haphazard nomenclature and an illogical classification, the study of these materials becomes one of absorbing interest and one of great profit for the highway engineer.

The geological origin of bitumen is, like that of many other common minerals, a matter of speculation and scientific controversy. Of the many theories that have been advanced, two stand

out as being most probable, but neither has been proven or disproven. The one is that bitumen is the result of chemical action which has taken place without heat, the various hydrocarbons making up the bitumen having been formed by the interaction of the several elements present in a manner unknown and unexplained. This is generally known as the inorganic theory. The other is that bitumen is the result of decomposition of either terrestrial or of marine animal or vegetable organic matter.

Either theory accounts for the complexity and variety of the bituminous materials that are now common articles of commerce and standard road-building materials.

Asphalt Defined.—Asphalts are now defined as follows: Asphalts are solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a complex mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Asphalts as here defined have a common property in that they are soluble to a greater or lesser degree in cold carbon disulphide or similar solvents, and experience indicates that the portion thus soluble is the binding or cementing agent in the compound.

Bitumen.—Bitumen is defined as a "mixture of native or pyrogenous hydrocarbons and their nonmetallic derivatives which may be gases, liquids, viscous liquids or solids, and which are soluble in carbon disulphide."

The first class of bitumens mentioned (gases) is of no interest to the road builder, but each of the others is used in some part of the art of road making.

Bitumen is a black or brownish-black substance, and that obtained from the various classes of road materials has very much the same general appearance. Some bitumens have distinct odors, especially when hot, and that of tar is easily recognized, while others have very little if any odor.

In physical characteristics the various bitumens differ greatly. Some are highly ductile, and others possess that characteristic to a very limited degree; some are brittle, others tough, some sticky, some greasy, some stable, some unstable.

In chemical characteristics there is also a great variation in the several classes of bitumens. They consist of mixtures of hydro-

carbons, mostly cyclic and bridge compounds, of great complexity. From the road builder's standpoint little or no attention is given to the chemical composition, except as the physical characteristics are affected thereby, and such relations are difficult to establish.

Since the value of the bituminous materials for highway purposes depends upon the character of the bitumen in them, most tests have for their object the determination of the character of the bitumen.

It is necessary to utilize bituminous materials that occur in nature or are made from materials thus obtained, and the character of a paving cement or binder can be controlled only to a somewhat limited extent. It is possible to mix two or more materials and thus produce a product differing from any of them in physical properties, but such a procedure does not necessarily produce a superior road material. Many commercial road and pavement materials, however, are produced in this way, it being possible to correct some one fault of a basic material by the mixture of some other product. As an example, mention might be made of the practice of mixing a highly ductile and brittle material with a "short" material to produce a road binder having reasonable ductility without being brittle.

It is not always possible to predict what durability will result from the mixture of two bitumens, and all such combinations should be worked out carefully in an experimental way before being undertaken on a commercial scale. Undoubtedly the manufacture of bituminous road materials in this way will be gradually perfected until compounds of specified properties and assured durability can be readily produced. At present, haphazard mixtures are looked upon with more or less suspicion because of numerous failures of pavements where such materials have been used. The compounding has had for its object the production of a material that will meet a certain specification, rather than the production of a good binder. This is more a fault of specification than of manufacture.

A peculiarity of bitumens is that there seems to be no definite and constant relation between their chemical and physical properties as determined by test, and the value of the bitumen as a paving material, that is applicable to all classes of bitumens. It is not always possible to examine and analyze an untried bituminous material and predict with certainty the behavior of the

material when subjected to traffic. The more experienced analysts are, of course, able to do so to a considerable extent, but even they occasionally err, and no basic and established laws have been promulgated.

It is apparent from what has been said that a bituminous cement cannot be manufactured to a standard formula as can Portland cement, but the engineer must use the materials that are produced commercially from the various classes of raw material, or mixtures of them.

Experience is the best guide in determining the value of any binder of this class, and until it has been successfully used for paving purposes it must be looked upon as an experimental product. On the other hand, many kinds of bituminous paving materials have been in continuous service for years so that their behavior has been well established.

Sources of Bituminous Materials.—From the standpoint of the highway engineer, all bituminous materials may be placed in three classes as follows: (*a*) natural asphalts, (*b*) petroleum asphalts, and (*c*) tars. This classification is an arbitrary one, but it is commonly employed.

NATURAL ASPHALTS

Natural asphalt is a bituminous material that is obtained from deposits existing in nature in which the material is of such character that it needs only to be freed of foreign matter to be suitable for use. This is the class of material originally known exclusively as asphalt.

Trinidad Asphalt.—The largest and best known of the natural deposits is that on the Island of Trinidad in the British West Indies, which is known as the Pitch Lake. This deposit is in the nature of a lake of about 125 acres extent and having a depth of more than 135 ft. in places. The material obtained from this deposit contains pieces of wood, gas, water, and a considerable quantity of fine sand and clay. The refined material is of uniform quality and contains 56.5 per cent. of pure bitumen, the remainder being sand, clay and organic matter insoluble in carbon disulphide. Other deposits of similar material are scattered over the islands, but they are of much less importance commercially. Trinidad asphalt has been long and widely used as a binder for sheet asphalt and asphaltic concrete pavements. It is unlike any other asphalt known.

Trinidad Petroleum.—A heavy asphaltic petroleum oil is obtained from wells on Trinidad Island, and this oil field has been extensively developed. This material contains a relatively small amount of the lighter oily constituents common to petroleum, and the body of the oil is of a truly asphaltic nature and exceedingly sticky and stable. This material is soluble in carbon disulphide to the extent of 99.9 per cent. It is refined and marketed as a dust layer and as a binder for the construction of bituminous carpets.

Bermudez Asphalt.—Another well-known deposit of natural asphalt is on the north coast of Venezuela and is known as the Bermudez deposit. It is a comparatively shallow deposit, being in most places about 7 ft. thick, but has an area of about 900 acres. The material has exuded from the earth and spread over a swampy area which is often covered with water. It contains decayed vegetable matter, sticks and a little clay and water. The water-free material is somewhat variable in composition and contains from 93 to 97 per cent. pure bitumen with an average of 95 per cent. The remainder is clay and organic matter insoluble in carbon disulphide. Bermudez asphalt is widely used as a binder for sheet asphalt, asphaltic concrete and macadam surfaces.

Cuban Asphalt.—Several deposits of natural asphalt exist in Cuba, most of which are of rather recent development. In general, the Cuban asphalt that has been utilized for paving purposes resembles slightly the Trinidad Lake asphalt, but is more variable in its characteristics. It contains from 65 to 75 per cent. of bitumen, the remainder being sand and clay and organic matter insoluble in carbon disulphide. Cuban asphalt is used to some extent for sheet and asphaltic concrete pavements, and for macadam surfaces.

Mexican Asphalt.—Deposits of natural asphalt also exist along the Gulf Coast of Mexico, and for a short distance inland in the Tuxpam district. These deposits are variable in composition, but are being developed rapidly and will likely be used extensively in the future. The various deposits contain from 60 to 99 per cent. pure bitumen. The Mexican asphalts have been used principally for sheet and asphaltic concrete surfaces.

Miscellaneous other deposits of natural asphalt are found throughout the world, and the material has been an article of commerce from the earliest times. Asphalt is found in the vicin-

ity of the Dead Sea, and its properties and value have been known locally from the earliest Bible times. The Dead Sea deposits have not been developed on a large scale. Other deposits in Asia and Europe have been known and utilized for centuries, and many European cities have been paved with asphalt obtained from these sources.

Deposits of minor importance are known in South America, and in Texas and California.

Gilsonite.—Deposits of a bitumen known as gilsonite, which is not an asphalt, are found in parts of Colorado and Utah. It is of importance because it is practically pure bitumen, and has been extensively used in the paving industry, being fluxed with an asphaltic residue and forming an exceedingly tough and rubbery cement.

Natural Rock Asphalt.—In many parts of the world there are extensive deposits of limestone or sandstone rock which by some process of nature have become impregnated with asphalt, usually in the form of a soft maltha. The best known deposits in the United States are in Kentucky, Oklahoma, Texas and Southern California, while those in Germany, France, Sicily and Russia are best known abroad. This class of material has had a limited use for sheet-asphalt surfaces in the United States, but has been extensively used in Europe. As might be expected, the rock asphalts vary greatly in character and few of them can be used for paving purposes without the addition of either sand or bitumen or both. The rock asphalts are also extensively used for mastic floors in factories and laboratories.

Refining Natural Asphalts.—It is doubtless apparent from the foregoing that the various materials discussed differ greatly in consistency and other physical characteristics, and that all must be prepared in some manner to render them suitable for paving purposes. In some of the deposits the materials vary from hard pitches to soft asphalts or malthas that flow slowly at ordinary temperature; in other deposits the consistency is fairly uniform.

A brief description of the method of refining the Trinidad Lake asphalt will indicate in a general way the usual preparation necessary before natural asphalts can be used for paving purposes.

The Trinidad Pitch Lake is some miles inland and about 140 ft. above sea level. The asphalt is broken out of the surface in irregular pieces by means of picks, and is loaded onto small cars. These are hauled out from the region of the lake and the remov-

able bodies of the cars attached to a cableway and transported to the dock where the material is loaded into vessels. When the cargo reaches the refinery (Maurer, N. J.) the asphalt is picked loose in the hold of the vessel and removed to the melting tanks. It is then heated by means of steam coils to a temperature exceeding 212°F., after which it is agitated by means of jets of steam from pipes in the bottom of the tank. As the heating progresses the entrained water and gas are given off and the sticks and other vegetable matter are removed. The material is then drawn off into barrels to be shipped to the place of use. There it is fluxed with a suitable petroleum oil to reduce its consistency to that desired for the paving cement.

PETROLEUM ASPHALTS

Petroleum, as is well known, is composed of complex and variable mixtures of hydrocarbon compounds, and, in the process of refining, the various burning and lubricating oils are distilled off, leaving a residue which is a black, viscous substance. The residue may consist of hydrocarbons of the paraffine series or may contain none of them, in which case it is called asphaltic, or it may be composed of both classes of material. Hence petroleums are referred to as asphaltic, semi-asphaltic or paraffine, depending upon the character of the basic compounds. The residue from the asphaltic and semi-asphaltic petroleums are converted into paving materials by various processes which will now be described briefly.

Residual Asphalts.—The residue from refining some kinds of petroleum is suitable for road construction without further treatment, and is marketed substantially as obtained in the process of refining the petroleum. This is particularly true of California and Mexican oils. In other instances the residues are either too hard or too soft and must be brought to a suitable consistency by variation in the refining process or by the addition of asphalts or fluxes from other sources. When an asphaltic material left from the refining process is suitable for use without further treatment, it is known as a residual asphalt. Residual asphalts are employed for dust laying, for carpeting, and for macadam construction, and when properly fluxed, for sheet pavements.

Gilsonite Products.—Some petroleum residues are unsuitable for paving purposes because of the poor quality of the bitumen

they contain, or because of their being of improper consistency. Gilsonite can be mixed with such of these residues as are of an asphaltic nature and thus produce a paving material of suitable character. The mixture may or may not be "blown" as described below. It is used for all classes of road construction where the mixing processes are employed, and for penetration macadam.

Blown Oils.—Petroleum residues are sometimes subjected to the process known as blowing, which improves them for use in paving work. The process consists in first heating the residue to a temperature of about 200°F. Air is then blown into the material from perforated pipes in the bottom of the tank, the heating being meanwhile continued. Under this treatment the temperature gradually rises to about 400°F. at which it is held until the material is brought to the desired consistency and quality. The process is usually continued for from 5 to 20 hr. With some grades of residue it is also necessary to add gilsonite or some other material rich in bitumen to produce a paving material of good quality. Products manufactured in this way are known as *blown oils.* The blowing has the effect of producing a waxy asphalt of low ductility but of reasonable stability. The blown oils are used for sheet asphalt and asphaltic concrete, and for mixed and penetration macadam construction.

TARS

Tar is classified commercially as a bituminous material, although the bitumen it contains is entirely unlike that contained in asphaltic materials.

Coal tar is a byproduct of the *destructive distillation* of coal. If the tar is produced during the manufacture of illuminating gas from coal, it is commonly called *gas-house tar.* If it is produced as a byproduct in the manufacture of coke, it is known as *coke-oven tar.* The gas-house tar is produced at a higher temperature than the coke-oven tar, and usually contains more free carbon (soot) than the coke-oven tar, due to the differences in processes of which the tars are a byproduct. Tars are almost pure bitumen, aside from the free carbon. They have the same general appearance as asphalts but have the characteristic and familiar tar odor which differs from the odor of any of the asphaltic materials. Tars are refined to prepare them for paving purposes,

the process consisting in distilling off the water and lighter or more volatile oils, leaving a residue of the desired consistency. Coal tar is used for penetration and mixed macadam, and for carpeting.

Cut-back Pitches.—Tars are used widely in the arts in obtaining the basic materials for dyes, medicines, etc., and incident to manufacturing these products, residues are often obtained that are too hard for paving purposes. These are softened or "fluxed" by means of lighter distillates obtained as a byproduct from other manufacturing processes and the resulting mixture is known as a *cut-back pitch* or simply as a "cut back." These tars are manufactured with various consistencies suitable for the different classes of macadam road work.

Water-gas Tar.—Water-gas tar is produced as a byproduct of the manufacture of illuminating gas from oil and water. It is the result of *destructive distillation* or "cracking" of a petroleum oil. It has the same general appearance as coal tar and has much the same odor, but is generally thought to be less useful for road purposes. It also differs in that it carries a much lower amount of free carbon than do the other classes of tars. It is refined and marketed for all classes of macadam construction.

Mixtures.—Many road binders and paving cements are mixtures of two or more of the classes or types of bituminous materials that have been mentioned. As an illustration, the practice of mixing California residues with Texas residues might be mentioned. Water-gas tars and asphaltic materials are also mixed in manufacturing some brands of road materials. These products often appear to have desirable physical properties, but their behavior under traffic has not yet been fully established.

Fluxes.—A flux is a soft bitumen or bituminous oil that is mixed with a harder bitumen to soften it. The ordinary asphalt cement is usually a mixture of a hard bitumen and a flux. The practice of softening a hard pitch with tar distillates has already been mentioned as a fluxing process and the distillate thus used is a flux.

Fluxes for asphaltic materials are obtained from petroleum and are of three classes, paraffine, semi-asphaltic and asphaltic, the classification depending upon the predominating basic compounds of which the flux is composed as has been mentioned in connection with petroleum asphalts. The paraffine fluxes are obtained to a limited extent from the petroleums of the Pennsyl-

vania and Ohio oil fields and to a large extent from those of Kentucky, Kansas, Oklahoma and Texas. It is the most commonly used of all the fluxes and when of the proper specific gravity and carefully manufactured so as to give uniformity is a satisfactory material for the purpose for which it is used.

Semi-asphaltic flux is obtained principally from Kentucky and Texas and only in limited quantities. As the name indicates, the basic compounds are partly asphaltic and partly paraffine. This is one of the best grades of flux obtainable.

Asphaltic flux is obtained principally from the California petroleums. It is a dense, heavy flux and a larger proportion of it must be used with a hard bitumen than of other types. When carefully prepared so that it will remain soft in the pavement, it can be used successfully.

The properties of fluxes obtained from the various sources will vary greatly, but certain characteristics are essential to all of them.

1. The flux should be prepared at high temperature, yet without injury to the material from overheating. It is essential that the paving cement in which the flux is used remain unchanged for years, and, unless the flux has been prepared at a temperature near 450°F., it is likely to volatilize in service and leave a brittle pavement surface.

Since the sheet asphalt and asphaltic concrete pavement surfaces are usually mixed at temperatures ranging from 250° to 350°F., it is necessary to use a flux that will not catch fire, *i.e.*, "flash" at these temperatures, which is an additional reason why the flux should be manufactured at high temperature.

2. The flux should be fluid enough to have the property of mixing with hard bitumens in such a manner that it will reduce the harder materials to a proper consistency without the necessity of using an excess of about 30 lb. of flux to 100 lb. of the harder bitumen. This characterisitic is only partly dependent upon the fluidity of the flux, being influenced also by the character of the hydrocarbons of which it is composed.

3. The flux should consist of stable compounds so that it will not change after it has been incorporated in the pavement. This property should not be confused with volatility. A volatile flux will evaporate and cause the pavement to become brittle. Other fluxes are composed of unstable compounds that change in the pavement with the passage of time. The result may be a bitu-

minous cement that is of good binding properties when the pavement is laid, but which loses its binding properties with time, and the pavement may fail as a result.

Asphalt Cement.—Asphalt cement is defined as a fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency so as to be suitable for direct use in the manufacture of asphaltic pavements, and having a penetration[1] between 5° and 250°. Generally it has a penetration between 40° and 70°. The asphaltic cement, as its name indicates, is an asphaltic material that is used to bind together the particles of sand or other mineral matter of which the pavement is composed. It is analogous in purpose to the Portland cement used in concrete.

The unfluxed asphalt cements are usually petroleum products, manufactured to the proper consistency for use without further treatment. They are received at the paving plant ready for use.

A fluxed asphalt cement is usually made at the paving plant. The hard asphalt and the flux are received separately and combined at the plant prior to mixing with the mineral aggregate.

CLASSES OF COMMERCIAL BITUMINOUS MATERIALS

(For explanation of the various tests, see Chapter XX)

Dust Layers for Earth Roads.—The materials prepared for this purpose are petroleum products of a semi-asphaltic or paraffine nature. They must be exceedingly fluid to mix with the soil and are usually applied cold. The following analysis indicates the general characteristics of materials obtained for this purpose. Many others have been used that differ more or less from this analysis, but this is one that has been used successfully:

Specific gravity at 25°C.	0 93
Fixed carbon	6.00 per cent.
Loss in 5 hr. at 163°C.	25 00 per cent.
(Residue from above slightly greasy).	
Specific viscosity (Engler) 50 c.c. at 50°C. .	46 00
Solubility in carbon disulphide....	100 00 per cent.
Bitumen insoluble in 86° naphtha	8.50 per cent.

Dust Layers for Gravel or Macadam.—The materials used for this purpose are slightly more viscous than those used on earth roads. They are commonly heated before being applied, but some kinds are applied cold. They may be petroleum products

[1] For definition of penetration, see Glossary.

or soft natural malthas, but the former are more widely used, while the latter are probably preferable. Light refined water-gas and coal-tar products are also extensively used for this purpose. If an oil is used, it should have a truly asphaltic base, and should have the property of hardening somewhat after application, that is, it should "set up" within a reasonable time. The following analyses and specifications will serve to indicate the nature of the tars and oils used for dust laying on macadam and gravel roads:

1. **Petroleum Oil** (Specification).—
   Specific gravity at 25°C. not less than 0.93.
   Solubility in carbon disulphide, not less than 99.5 per cent. and not over 0.3 per cent. of organic insoluble matter.
   Bitumen insoluble in 86°Bé. naphtha not less than 3 per cent. nor more than 15 per cent.
   Specific viscosity (Engler) 50 c.c. at 50°C. between 40 and 80.
   Fixed carbon, not less than 3.5 per cent.
   Loss on heating at 163°C. for 5 hr., not more than 20 per cent. (Residue must not be greasy.)

2. **Asphaltic Oil** (Soft maltha, analysis).—

Specific gravity at 25°C.	0 961
Consistency by float test at 50°C.	10 00 sec.
Loss on heating 5 hr. at 163°C.	26 10 per cent.
(Residue sticky and asphaltic).	
Consistency of residue by float test at 50°C. 2 min. 25 sec.	
Solubility in carbon disulphide	99 95 per cent.
Organic matter insoluble in carbon disulphide.	0.05 per cent.
Bitumen insoluble in 86°Bé. naphtha.	8 20 per cent.
Fixed carbon.	3 70 per cent.

3. **Light Refined Tar** (Analysis).—

Specific gravity at 25°C.	1 16
Consistency by float test at 50°C.	25 sec.
Free carbon	4 40 per cent.
Distillation.—	
Distillate to 110°C.	0 00 per cent.
Distillate from 110° to 170°C.	0 00 per cent.
Distillate from 170° to 270°C	34 00 per cent.
Pitch	66 00 per cent.

Bituminous Carpets.—Bituminous materials and stone chips or screened gravel are applied to macadam road surfaces so as to build up a layer of appreciable thickness. Such a coating is called a "bituminous carpet" or the process is referred to as bituminous surfacing. The asphaltic products and the tars are used for this purpose, and the following are analyses of materials

that have been successfully employed. Similar materials are employed for carpeting concrete road surfaces, but not with the same degree of success.

1. Asphaltic Materials (Analysis).—

Specific gravity at 25°C. .	0 989
Flash point.	110°C.
Burning point. . .	130°C.
Consistency by the float test at 50°C.	20 sec.
Loss on heating for 5 hr., at 163°C. (Residue very sticky, asphaltic).	15.9 per cent.
Consistency of residue by float test at 50°C., 2 min. 30 sec.	
Bitumen soluble in carbon disulphide	99 9 per cent.
Organic insoluble matter.	0 0 per cent.
Bitumen insoluble in 86° naphtha.	10 1 per cent.
Fixed carbon.	5.9 per cent.

2. Refined Coal Tar (Analysis).—

Specific gravity at 25°C.	1 22
Consistency by float test at 50°C.	38 sec.
Free carbon.	18 00 per cent.

Distillation.—

Distillate to 110°C.	0 0 per cent.
Distillate between 100° and 170°C.	1 0 per cent.
Distillate between 170° and 270°C.	28 0 per cent.
Pitch residue	71 0 per cent.

Penetration Macadam.—This type of surface differs from the bituminous carpet in that the bituminous material is applied at the time the stone is placed, and in a manner to insure that the binder will penetrate an inch or more into the surface. Natural and petroleum asphalts and refined tars are used successfully. The following specifications cover the three classes of material usually employed for this purpose:

1. Refined Tar (Specification).—

Specific Gravity.—The specific gravity at 25°C. shall not be more than 1.26.

Free Carbon.—The free carbon shall not exceed 20 per cent. by weight.

Consistency.—The consistency as determined by the Howard and Morse float apparatus at a temperature of 50°C. shall not be less than 1½ min. nor more than 2½ min.

Distillation.—Fractional distillation shall give results within the following limits, all measurements being by volume:

Up to 110°C. the distillate shall not exceed 2 per cent.

Up to 170°C. there shall be not to exceed 5 per cent. distillate of which not more than one-fourth shall be naphthalene.

The total distillate up to 315°C. shall be at least 18 per cent.

2. **Natural Asphalts and Gilsonite Products** (Specification).—The material shall be free from water.

   Specific Gravity.—The specific gravity at 25°C. shall not be less than unity.

   Total Bitumen.—The bituminous material shall be soluble in chemically pure carbon disulphide at air temperature to the extent of at least 99.5 per cent. for residual asphalts and gilsonite products, 95 per cent. for Bermudez products, 80 per cent. for Cuban products, and 65 per cent. for Trinidad products.

   Naphtha Insoluble Bitumen.—Of the total bitumen not less than 15 per cent. nor more than 28 per cent. by weight shall be insoluble in 86°Bé. paraffine naphtha at air temperature. On evaporation of the naphtha solution the residue obtained shall be sticky and not merely oily.

   Fixed Carbon.—The fixed carbon shall be not less than 8.0 per cent. nor more than 14.0 per cent.

   Penetration.—The penetration as determined with the Dow penetration machine, using a No. 2 needle, 100 grams weight, 5 sec. time, and a temperature of 25°C., shall not be less than 14 mm. nor more than 16 mm.

   Loss on Evaporation.—When 20 grams (in a tin dish 2⅜ in. in diameter and ¾ in. deep, with vertical sides) are maintained at a temperature of 163°C. for 5 hr., the loss shall not exceed six (6 0) per cent. by weight. The surface of the residue at air temperature shall be smooth and show no sign of blistering or cracking, and when tested the penetration in 5 sec. at 25°C. with a No. 2 needle, and 100 grams weight, should be at least five (5.0) millimeters.

   Ductility Test.—The ductility at 25°C. shall not exceed eighty-five (85) centimeters.

   Flash Test.—The flash point in an open cup shall not be less than 163°C.

   Paraffine Scale.—The asphaltic binder shall not contain more than two (2.0) per cent. by weight of paraffine scale.

3. **Petroleum Products** (Specification).—

   The bituminous material shall be free from water.

   Specific Gravity.—The specific gravity at 25°C. shall not be less than 0.965 nor more than unity.

   Total Bitumen.—The bituminous material shall be soluble in chemically pure carbon disulphide to the extent of at least 99½ per cent. by weight at air temperature.

   Naphtha Insoluble Bitumen.—Of the total bitumen not less than 20 nor more than 26 per cent. by weight shall be insoluble in 86°Bé. paraffine naphtha at air temperature. On evaporation of the naphtha solution, the residue should be sticky and not merely oily

   Loss on Evaporation.—When 20 grams (in a tin dish 2⅜ in. in diameter and ¾ in. deep, with vertical sides) are maintained at a temperature of 163°C. for 5 hr., the loss shall not exceed 2 per cent. by weight. The surface of the residue at air temperature shall be smooth and shall present no greasy spots nor any sign of blistering or cracking. The penetration in the residue shall not be decreased more than 40 per cent. from the original consistency.

Fixed Carbon.—The fixed carbon shall not be less than 7 nor more than 13 per cent.
Penetration.—The penetration, using a No. 2 needle, 100 grams weight, 5 sec. time, and a temperature of 25°C. shall not be less than 7 nor more than 12 mm.
Carbenes.—The bituminous binder shall not contain more than ½ per cent. by weight of bitumen insoluble in chemical pure carbon tetrachloride at air temperature.
Flash Test.—The flash test in open cup shall not be less than 200°C.
Melting Point.—The melting point shall not be less than 60°C.
Ductility.—The ductility at 25°C. shall not be less than 25 cm., according to the District of Columbia standard.

Macadam Constructed by the Mixing Methods.—This type of construction lies between the penetration macadam and the asphaltic concrete, and the bituminous materials used are of the same general character as those used in penetration macadam. The following analyses will illustrate the kind of material that has been successfully used for this purpose.

Asphaltic Binder.—

Specific gravity at 25°C.	1.06
Consistency by penetration at 25°C., 100 grams, 5 sec., No. 2 needle	72°
Loss in heating 5 hr., at 163°C.	4 26 per cent.
Penetration of residue as above, relative to original	36 00 per cent.
Solubility in carbon disulphide	95 6 per cent.
Insoluble organic matter	1 2 per cent.
Bitumen insoluble in 86° naphtha	26 6 per cent.
Fixed carbon	11.1 per cent.

Tar Binder.—

Specific gravity at 25°C.	1 24
Consistency by the float test 65°C.	55 sec.
Free carbon	22 0 per cent.
Distillation.—	
To 110°C.	0 4 per cent.
110° to 170°C.	4 4 per cent.
170° to 270°C.	22 0 per cent.

Asphaltic Concrete.—The requirements of the bituminous material for this class of construction are more rigid than for the other types of bituminous pavement. Practice is confined almost entirely to the use of asphaltic materials and frequently the asphalt cement is manufactured at the paving plant as has been mentioned before. It is not possible to draw satisfactory exact specifications that will cover all classes of good asphalt

cements, but general specifications are sometimes drawn under which any suitable material may be used. Such general specifications are in reality a combination of class specifications. The following is an example, and it should be noted that the use of a manufactured asphalt cement, or one prepared at the paving plant, is permitted.

REFINED ASPHALT[1]

The refined asphalt to be used for paving mixtures shall be derived in the following manner:

1. By heating, if requiring refining, crude, native, solid asphalt to a temperature of not over four hundred and fifty (450) degrees F. until all water and light oils have been driven off. Crude, native, solid asphalt shall be construed to mean any native mineral bitumen, either pure or mixed with foreign matter having a consistency harder than one hundred (100) degrees penetration. At least ninety-eight and one-half (98½) per cent. of the contained bitumen in the refined asphalt which is soluble in cold carbon disulphide shall be soluble in cold carbon tetrachloride.

2. By the careful distillation of petroleum with steam agitation, at a temperature not exceeding seven hundred (700) degrees F., until the resulting residue has a consistency not harder than thirty (30) degrees penetration.

(*a*) The solid residue so obtained shall be soluble in carbon tetrachloride to the extent of ninety-eight and one-half (98½) per cent.

(*b*) If the solubility in carbon tetrachloride of the solid residue is less than ninety-nine (99) per cent., the bitumen shall yield upon ignition not more than fifteen (15) per cent. of fixed carbon; if the solubility is ninety-nine (99) per cent. or more, the bitumen shall yield upon ignition not more than eighteen (18) per cent. of fixed carbon.

(*c*) When twenty (20) grams of the material are heated for five (5) hours at a temperature of three hundred and twenty-five (325) degrees F. in a tin box two and one-quarter (2¼) inches in diameter, after the manner officially prescribed, it shall lose not over five (5) per cent. by weight nor shall the penetration after such heating be less than one-half the original penetration.

(*d*) When the refined asphalt is brought to a penetration of

[1] Recommendation of the Association for Standardizing Paving Specifications.

fifty (50) by the use of the flux with which it is to be combined in making the asphaltic cement, or by heating at a temperature below five hundred (500) degrees F., it shall have a ductility of not less than thirty (30) centimeters.

(*e*) All shipments of material shall be marked with a lot number and penetration, and then ten (10) samples taken at random from each lot shall not vary more than fifteen (15) per cent. from the average penetration.

3. By combining crude, native, solid asphalt with asphaltic or semi-asphaltic flux of the character hereinafter designated, provided that the proportion of the flux to the contained bitumen of the crude asphalt does not exceed forty (40) per cent. by weight or result in a refined asphalt having a penetration greater than forty (40) degrees.

In the use of combinations of refined asphalts for asphaltic cement, only asphaltic or semi-asphaltic fluxes shall be used, except in those cases where the solid natural asphalt is of such character that when mixed with paraffine flux without the addition of any other material it will produce an asphaltic cement complying with the requirements set forth under that head. In such cases any of the fluxes elsewhere specified may be used.

FLUX

The flux material may be a paraffine, asphaltic or a semi-asphaltic residuum which shall be tested with and found suitable to the asphalt to be used and must have a penetration greater than three hundred (300) degrees with a No. 2 needle at seventy-seven (77) degrees F. under fifty (50) grams weight applied for one (1) second. All residuums shall be soluble in cold carbon tetrachloride to the extent of ninety-nine (99) per cent.

(*a*) The paraffine residuum shall have a specific gravity of ninety-two hundredths (0.92) to ninety-four hundredths (0.94) at seventy-seven (77) degrees F. It shall not flash below three hundred and fifty (350) degrees F. when tested in a New York State closed oil tester, and shall not volatilize more than five (5) per cent. of material when twenty (20) grams are heated five (5) hours at three hundred and twenty-five (325) degrees F. in a tin box two and one-quarter (2¼) inches in diameter as officially described.

(*b*) The semi-asphaltic residuum shall have the same general

characteristics as paraffine residuum, except that it shall have a specific gravity of ninety-four hundredths (0.94) to ninety-eight hundredths (0.98) at seventy-seven (77) degrees F. It shall have a viscosity coefficient at two hundred and twelve (212) degrees F. of less than sixteen (16) Engler viscosimeter.

(*c*) The asphaltic residuum shall have the same general characteristics as paraffine residuum except that the specific gravity shall be not less than ninety-eight hundredths (0.98) nor more than one and four hundredths (1.04) at seventy-seven (77) degrees F. The asphaltic residuum after evaporation at five hundred (500) degrees F. to a solid of fifty (50) to sixty (60) penetration shall have a ductility of not less than thirty (30) centimeters.

ASPHALTIC CEMENT

The asphaltic cement shall be prepared from the refined asphalt or asphalts and flux, where flux must be used, above designated, provided that mixtures of the refined asphalts, if used, shall be equal parts of each, and that the total proportion of refined asphalt or asphalts comprising the asphaltic cement shall be not less than fifty (50) per cent. by weight.

When the weight of flux in the asphaltic cement prepared from solid native asphalts exceeds twenty-five (25) per cent. thereof, asphaltic or semi-asphaltic flux shall be used.

The refined asphalt and flux used in preparing the cement shall be melted together in a kettle at temperatures ranging from two hundred and fifty (250) degrees to not over three hundred and seventy-five (375) degrees F., and be thoroughly agitated when hot by air, steam or mechanical appliances, until the resulting cement has become thoroughly mixed into a homogeneous mass. The agitation must be continued during the entire period of preparing the mixtures. The cement shall always be of uniform consistency and if any portion should settle in the kettles between intervals of using the same, it must be thoroughly agitated before being drawn for use.

(*a*) The asphaltic cement shall have a penetration of from thirty (30) to eighty-five (85) degrees, which shall be varied within these limits to adapt it to the particular asphalt used in the paving mixtures and to the traffic and other conditions of the street.

(*b*) When fifty (50) grams of the asphaltic cement of the con-

sistency used in the paving mixture shall be heated for five (5) hours at a temperature of three hundred and twenty-five (325) degrees F., in a tin box two and one-quarter ($2\frac{1}{4}$) inches in diameter, there must not be volatilized more than five (5) per cent. of the bitumen nor shall the penetration at seventy-seven (77) degrees F. after such heating be less than one-half of the original penetration.

(*c*) A briquette of the asphaltic cement of the consistency used in the paving mixture shall have a ductility of not less than ten (10) centimeters.

Asphalt Cement for Sheet-asphalt Pavements.—The specifications given above will also cover the requirements of this class of work but the consistency will vary in different localities depending upon climatic conditions and the class of traffic on the pavements. Generally the A. C. for sheet pavements is 10° harder than for asphaltic concrete in the same locality.

FILLERS FOR BRICK AND BLOCK PAVEMENTS

The essential characteristics of a bituminous filler for expansion joints and for filling the joints between the courses of a block pavement are:

1. The filler must adhere to the brick or block readily so as to completely fill the joint.

2. The filler must remain sufficiently ductile at the lowest temperature to which it is subjected to accommodate itself to any movement of the pavement. It must also be sufficiently stable at the highest temperature to which it is subjected to remain intact in the joint rather than to flow slowly to the lower part of the pavement.

3. The filler must possess sufficient toughness at low temperature to resist the abrasive action of traffic.

4. The filler should be proof against the destructive action of water and street liquids.

The following is a general specification covering a suitable material of any class:

The filler must have a melting point varying not more than 5° from 135°F. and must not be brittle at zero F.; it shall remain ductile, shall be absolutely proof against water and street liquids, shall firmly adhere to the brick and stone, be pliable rather than rigid, thus providing for expansion and contraction and traffic conditions.

The following specification provides for a suitable grade of asphalt filler:

1. The asphalt filler shall have a specific gravity of not less than 0.98 nor more than 1.04.

2. It shall be soluble in chemically pure carbon disulphide to at least 99.5 per cent.

3. It shall contain not less than 25 nor more than 40 per cent. of bitumen insoluble in 86°Bé. paraffine naphtha.

4. The penetration shall conform to the following limits for the conditions stated:

At 25°C., No. 2 needle, 100 grams, 5 sec.—2.5 to 5.0 mm.

At 4°C., No. 2 needle, 200 grams, 1 min.—not less than 2.0 mm.

At 46°C., No. 2 needle, 50 grams, 5 sec.—not more than 10.0 mm.

5. The melting point as determined by the cube method shall not be less than 80°C. nor more than 120°C.

6. It shall be free from water and shall not foam when heated to 350°F.

The following specification covers a suitable grade of tar filler:

1. The filler must be obtained wholly from coal tar without the admixture of any other material.

TABLE 18.—SOME PROPERTIES OF VARIOUS BITUMINOUS MATERIALS

Material	Specific gravity	Solubility in CS_2, per cent.	Fixed carbon, per cent	Asphaltenes in the bitumen, per cent.	Carbenes in the bitumen per cent.
Trinidad asphalt.....	1.4	56 0	10–11	37	1.3–1 6
Trinidad asphalt cement.	1.25–1 30	65 0	10–12	20–30	1 0–1.5
Cuban asphalt..........	1.30–1.35	65–75	15–25	30–50	1 5
Grahamites...	1.12–1.17	99.5+	30–50	only slightly soluble	20–45
Maracaibo asphalt........	1.06–1.08	90–98	15–20	45–55	1.2–1.7
Bermudez asphalt	1.05–1.08	93–95	10–15	15–25	1.5
Gilsonite	1.04–1 08	99 5	12–14	30–50	±0.5
California residuals	1.00–1.03	99 5+	12–15	20–30	±0.5
Mid-Continent residuals.	0.97–1.00	99.0+	10–15	15–25	±0.5
Paraffine fluxes..........	0.90–0.95	99 5+	......	.....	1.0–0.5
Semi-asphaltic fluxes.....	0.94–0.98	99.5+	....	.....	1.0–0.5
Asphaltic fluxes.........	0.96–1.04	99.5+	......	.....	1.0–0.5
Blown oils.............	0.97–1.00	99.5+	10–15	20–30	±0.5
Mexican................	1.02–1 05	99.5+	12–20	25–35	+0.5

2. Specific gravity at 25°C., 1.17 to 1.30.
3. Free carbon, 22 per cent. to 37 per cent.
4. Distillation of 100 grams to 600°C. shall give not to exceed 8 per cent. of distillate.
5. Melting point, 130°F. to 140°F.
6. Penetration at 100°F., 5 sec. under weight of 50 grams not less than 30°.

Specifications for creosote oils for paving blocks are discussed in the chapter on Wood-block Paving.

CHAPTER XIV

DUST LAYERS AND BITUMINOUS CARPETS

I. DUST SUPPRESSION ON EARTH ROADS AND STREETS

The earliest attempts to use asphaltic oils and petroleum residues for laying the dust and preserving the surface of earth roads and streets were made in California. On account of the nature of the soil and the excellent quality of the oils available, the California experiments gave promising results and attracted wide attention. Similar attempts in other portions of the United States and with oils of a different kind and under other soil and climatic conditions have not been so successful. This is particularly true of those attempts that have been made to secure permanent results with mixtures of heavy asphaltic oils and earth. In most cases the results have been of little value and have almost universally failed if the roads carried heavy traffic.

Where oils of a more fluid nature have been used to suppress the dust on earth roads the results have been more satisfactory and there has been a gradual increase in the use of such oils for dust prevention.

Preparation.—If a road or street is to be oiled for the first time, preparations should be started some weeks before the oil is actually applied.

The effect of the oiling is to render the earth partially impervious to moisture and if the surface of the road be uneven when oiled or becomes uneven afterward, the depressions will become basins for holding water. Traffic will gradually work the soil and the water thus retained into mud, deepening the depressions to the serious detriment of the street. If the street be smooth and well crowned the water will run to the gutters so quickly that only in long-continued wet weather will the street be softened to any great extent and therefore traffic will not make any considerable amount of mud on the surface.

The principal object in oiling a street is to prevent dust; therefore, there should be no dust on the street when the oil is applied. If dust has formed, it had better be removed, which costs something. It is therefore cheaper to treat the surface before the dust has formed, if possible.

For the best results the street oiling should be planned ahead and the preparation of the street be carried out in the early summer so that the oiling can be done before a layer of dust forms on the street.

Grading.—Good results with oil cannot be expected on a flat and poorly drained street. Early in the summer the street should be carefully rounded with an even slope from the middle to the gutter. The gutter or ditch should be deep enough to readily carry the water and to permit a slope of about an inch to the foot from the middle of the street to the gutter. Generally the bottom of the gutter should be about 18 in. below the middle of the street where the width of the street is not over 35 ft. between gutters. This is about right on a residence street. On a business street having a width of 50 ft., the bottom of the gutter should be at least 2 ft. below the middle of the street.

After the street has been shaped with a grader, it will undergo a period of settling during which some depressions and uneven places will appear. These should be filled with earth and the entire roadway be kept dragged until it finally becomes hard and smooth and free from depressions.

It is very important to secure a firm, smooth surface for the oil, and the small expense incurred will be more than made up by the increased effectiveness of the oil treatment.

When the street has been brought to this stage it is ready for oiling. If the oiling is delayed until a layer of dust has formed on the street it is best to scrape off most of it before oiling.

The decision to oil a street may sometimes be reached after the summer is well along and the streets have become hard and dry. In that event, it is not advisable to do any extensive earthwork because in continued dry weather newly placed earth will not compact readily and if oiled before well packed the results are unsatisfactory. Such a condition is not ideal and only mediocre results can be expected.

Kinds of Oils to Use.—The various kinds of oils employed for this purpose have already been discussed at length in Chapter XIII.

Applying Oil.—After the street has been prepared as described, the oil is applied at the rate of not less than 1/3 gal. nor more than 1/2 gal. per square yard of surface. If the street has never been oiled before, or if more than a season has elapsed since a previous oiling, it will be necessary to use about 1/2 gal. per square yard, but if the street has been oiled regularly each season, about 1/3 gal. per square yard is sufficient after the first year. For a street in a small-town business district, it is necessary to oil every year, using about 1/2 gal. per square yard of surface for each oiling. In many towns it is desirable to oil the business streets twice a year.

After the oil has been spread it is allowed to stand without

FIG. 64.—An oiled earth road.

being covered for about a day, to permit it to soak into the surface. It is then covered with just enough sand to keep the oil from picking up. Emphasis is placed on the importance of employing sand for this purpose rather than dust from the old road surface. The amount of sand needed is small and at any reasonable price the benefits derived from the sand justify its use wherever it can be secured.

After the road has been put into service it may be apparent that more sand is needed in spots to prevent vehicles from picking up the oil, and such places should be covered lightly, the operation being repeated two or three times if necessary.

When a street is oiled the second time, the method to be followed is exactly the same as is followed the first time, except that the quantity of oil may be reduced to about $\frac{1}{3}$ gal. per square yard of surface. It is advisable to repeat the oiling the second year in any case, and it may be then omitted the third year and resumed the fourth year. Better results would be obtained if the treatment were repeated every year.

Results to be Expected.—Surface oiling forms a surface covered with a layer of granular or finely powdered soil which is oil-saturated and consequently does not blow about readily. The suppression of dust is the principal benefit to be expected. Beneath the thin layer of loose, oil-soaked soil the firmer portion of the street is saturated with oil for a depth that varies from 1 in. to perhaps 6 in.

Water penetrates this layer rather slowly. If the street has plenty of cross-slope so that water does not stand on the surface, only a small amount of mud will form under light or moderate traffic. A street that is oiled systematically for a series of years gradually acquires an oil-soaked crust which becomes more and more impervious as the oiling is repeated. An oiled street never gets to the place where it will not be muddy in those seasons of heavy rainfall nor will the surface be stable in ordinary wet weather if the road carries a heavy traffic.

Unloading the Oil from Tank Cars.—The oils used for dust suppression can be purchased so much more cheaply in tank-car lots than in barrels that it is always advisable to purchase in such lots. If a siding on an embankment 8 or 10 ft. high is available, the car can be placed thereon and the oil allowed to run into the sprinkler wagon through a pipe connected to the tap in the bottom of the tank car.

When such a siding is not available the oil must be pumped from car to wagon. For this purpose the ordinary tank pump used with traction engine tanks is as good as anything. It should be placed on top of the tank car with all connections made of pipe, as hose does not last long in oil. If a small steam or gas engine driven pump be available, it will, of course, be faster than a hand pump.

Cost of Surface Oiling.—The total cost of oiling earth roads or streets will vary between the following limits, assuming a treatment of $\frac{1}{2}$ gal. per square yard of surface, and the cost of oil to be 4 cts. per gallon.

TABLE 19.—COST PER SQUARE YARD FOR OILING

Item	Min	Max.	Aver.
Cleaning surface	0 0025	0 0050	0.00375
Hauling and distributing oil and sanding.	0 0075	0 0125	0.0100
Cost of oil	0 0200	0 0400	0 0300
Cost of sand	0 0025	0 0075	0 0050
	0 0325	0 0650	0 04875

II. DUST SUPPRESSION ON GRAVEL AND MACADAM

The use of oils for dust suppression must not be confused with the construction of the bituminous wearing surface or carpet which will be described later. For dust laying, the object sought is to mitigate the disagreeable characteristics of the ordinary gravel or macadam road without attempting to use a type of oil or method of construction that will preserve the surface to any considerable degree.

Dust results from the wearing or loosening of particles of the road surface and from the grinding up of soil carried onto the surface from adjacent earth roads or streets. To this may be added droppings from horses, material that leaks from vehicles during the time it is being transported over the road, and a small amount of miscellaneous refuse of unclassified origin. The process of dust suppression does not contemplate the prevention of dust from these sources, but merely a treatment that will prevent it from blowing about. This is accomplished by periodical sprinkling with an oil that possesses sufficient binding power to hold the particles together and prevent them from being carried away by the wind. The bituminous materials suitable for this purpose have already been discussed in Chapter XIII.

As with earth surfaces, the gravel or macadam surface should be practically free from dust when the oil is applied, and should be smooth and true to cross-section. If repairs are necessary these should be made some weeks prior to oiling if possible so as to give the new material time to compact in place before being oiled.

The oil must be applied with more care than on earth roads because less will be absorbed and an excess will be disagreeable.

One of the multiple-nozzle pressure distributors described in Chapter XV is best adapted for the work, and the oil or tar may be applied hot or cold, depending upon the grade used.

A first application usually consists of ½ gal. per square yard of surface, and subsequent applications of ¼ to ⅓ gal. per square yard. If, however, too long a time elapses between treatments, it would, of course, increase the quantity of oil needed. Two applications the first season and one each succeeding season usually suffice, but this also depends upon the character and amount of traffic and the nature of the surface.

It has been shown that repeated oiling will gradually render

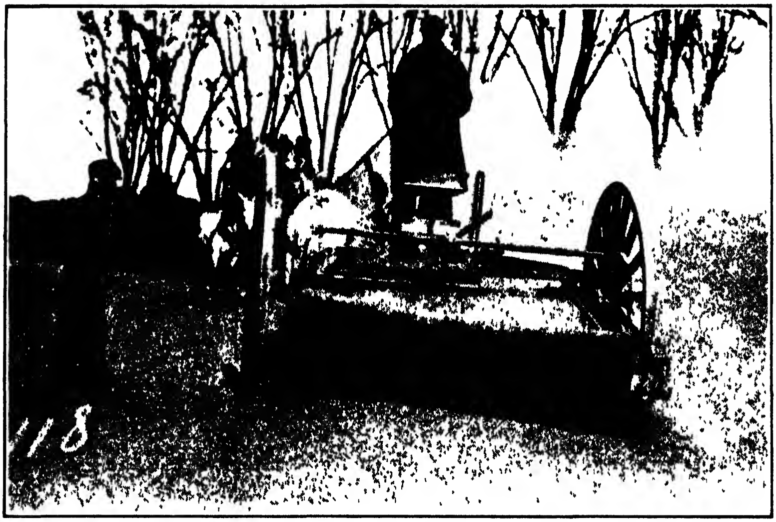


FIG. 65.—Cleaning a surface for carpet coating.

the surface impervious to water and cement the particles together to a limited degree, especially if a good grade of oil or tar is applied. On the other hand, there is some danger of introducing into the surface an oil that will act as a lubricant instead of as a binder, and in that event the road will become loose and rapidly develop pot holes and ruts under traffic. Considerable difficulty has been experienced throughout the United States from that source and too much emphasis cannot be put on the importance of using a good asphaltic base oil or a suitable grade of tar.

While it is desirable to cover the oil with a light dressing of

coarse sand or screenings, it is possible to overdo the matter and thus offset to some extent the benefit of the oil. One cubic yard of the sand or screenings should cover at least 200 sq. yd. of surface.

Light oils and tars are also used for the suppression of dust on broken stone roads and the general principles that have been discussed in connection with gravel roads apply to macadam roads as well. Since the macadam surface is hard to clean, it is advisable when possible to apply the oil before the surface becomes dusty. When a new road is put in service, traffic will gradually brush off most of the excess of screenings and there will follow an interval when the surface is almost bare. Later the stone may begin to wear and produce more dust or the

Fig. 66.—Applying the oil for a carpet coat.

larger stones may loosen and work out on the surface. In either case the surface has gone beyond the proper stage for oiling. The oil or tar used on macadam surfaces is of the same character as is used on a gravel road and the method of application and quantity varies in the same way. The use of greasy oil is even more detrimental to macadam than to gravel.

The oils and tars used for dust suppression on gravel and macadam surfaces range in price from 4 to 7 cts. per gallon and the cost of application varies from ½ to 2 cts. per gallon. The actual cost of oil treatments has generally been from 3 to 5 cts. per square yard of surface for each application.

Oil on Hard Pavements.—Light oils have been used to a limited extent on brick and concrete pavements for the sup-

pression of dust, but definite conclusions as to the desirability of the practice have not been reached. It seems probable that where systematic flushing cannot be carried out, the oil may serve to palliate the dust nuisance. Emulsions of oil and water have also been employed to a limited extent with only small success.

Other Palliatives.—Many proprietary compounds have been advanced from time to time as dust preventatives. The most widely used have either been hygroscopic salts or semi-sticky byproducts soluble in water. These compounds are usually of only temporary effect and have not come into wide use.

Water is, of course, the most common form of palliative and needs no discussion in this connection. Water sprinkling must be kept up with great regularity in hot weather to be of benefit, and is the most expensive method of dust suppression, and at the same time one of the least effective.

BITUMINOUS CARPETS

Purpose.—A bituminous carpet serves several distinct purposes: (*a*) it prevents the formation of dust by attrition of the

FIG. 67.—Spreading the oil with a brush.

road surface; (*b*) it has a tendency to catch and hold dust carried onto the surface from external sources; (*c*) it forms a somewhat elastic cushion, thereby increasing the comfort of those who use the pavement; (*d*) it renders less noisy hard surfaces; (*e*) it takes the wear, thus preserving the material upon which it is placed; (*f*) it prevents the removal of the binder from a gravel or macadam surface by automobiles.

Requirements of Bituminous Material.—It is apparent that a thin layer of plastic material placed on top of a hard surface will be subjected to constant kneading from the rolling wheels and the hoofs of animals, which will work into it such inert material as may be deposited on the surface. The kneading will also have a tendency to shear the bituminous layer from the rigid material under it and the constant addition of inert matter will gradually reduce the ability of the bituminous material to accommodate itself to the constant slight motion. Necessarily then, the bitumens used for "carpets" must be ductile and adhesive and must be of a stable and durable nature. The materials employed for this purpose are described in Chapter XIII.

Fig. 68.—Showing the effect of using an excess of oil.

The bituminous surface is used on gravel, broken stone, and to a limited extent on concrete roads and pavements. It was first adopted for use on macadam to prevent destruction by automobiles, but has been recognized for its value in the other particulars mentioned and is now one of the standard maintenance methods for gravel and macadam roads.

The bituminous carpet is employed under two widely different conditions: (1) to a newly completed gravel or broken-stone macadam; (2) to a badly worn gravel or broken-stone macadam, or one that has been under traffic for some time. The purpose of the surfacing is the same in both cases, but the method of preparation is somewhat different.

Applying the Bituminous Carpet to a New Road.—Both the gravel and the macadam type of surface depend for their stability upon the binding properties of the finer material in the surface. This may be stone dust or silt and clay. It is not desired to replace this binding material with the bituminous binder but rather to insure its retention in the surface. Accordingly roads that are to be surfaced with a bituminous material are finished as water-bound surfaces.

It is customary to finish these surfaces with some excess of binder, that is, with some fine material on the surface for reasons already explained (Chapter VIII). The bituminous material

FIG. 69.—Covering the oil with chips.

cannot be applied successfully to a dusty surface. Therefore, a newly constructed road is opened for traffic for a time to permit it to "season" or compact and to bring to attention any weak places that may have been overlooked during the construction. This may require only a few weeks if the traffic is heavy, or it may require several months. During this period the fine material will be gradually brushed and blown from the surface by traffic and eventually it will approach the proper condition for bituminous surfacing. The surface to be covered should have a close-knit texture, but be free of dust and loose chips or pebbles. The binder between the stones should be intact, but the surface itself should be clean and free of the screenings or other bonding

material. There should be no ruts or depressions in the surface, or, if any have developed, they should be repaired. It is not usual to find the surface clean across its entire width, and the outer portion will usually require sweeping which may be done with a power machine or by hand.

When the surface is properly prepared the bituminous material is spread with the pressure distributor which is the only machine that can be successfully used for the work.

The quantity of bituminous material applied ranges from ⅓ gal. to ¾ gal. per square yard of surface, with ½ gal. as about the average treatment. If for any reason an excess of the bituminous material is used in spots, these places should be broomed

Fig. 70.—Oiled gravel road.

to thin them out. With care and a good machine such instances will be rare. The best results are obtained when the material is spread out.

After the road has been covered, a thin layer of torpedo gravel or of stone chips is spread over the bituminous material. The success of the treatment depends very greatly on the class of material that is used to cover the bituminous coating. It must be apparent that the thin layer of plastic surface will be subjected to severe treatment and if soft screenings or chips are used they will grind up quickly and lose their value. Granite or trap or equally hard stone chips must be used. If a clean coarse torpedo sand is available it will be satisfactory, provided it is not too fine. A size passing a ½-in. screen and containing little material

that will pass a ⅛-in. screen is about right. Chips may be graded from ¾ in. or 1 in. down, but should contain no dust.

The chips or sand is applied sparingly, being spread on from piles alongside the road. Just enough should be used to prevent the bituminous material from picking up on the wheels of vehicles. It is difficult to judge beforehand just how much will be required and it is good practice to put on a light coating and open the road for traffic and then to add more as the need becomes apparent. The surface should be rolled thoroughly to set the chips in the surface.

Since the bituminous carpet does not penetrate the surface appreciably, it depends for its stability upon adhering to the stones of the road. A greasy material or one lacking ductility is certain to give disappointment.

The surface produced will be black after a few weeks of use, will be ¼ to ⅜ in. thick and will be ductile and show the imprint of wheels or hoofs readily. Its life is variable but usually is about two seasons. The cost ranges from 3 to 6 cts. per square yard of surface exclusive of the cost of minor repairs to the surface.

Bituminous Carpets on Worn-gravel and Macadam Roads.—Many broken-stone and gravel roads were built before the advent of heavy motor traffic and these have sufficed until recent years. With the ever-changing routes of travel such roads are constantly becoming a part of a motor route and bituminous surfacing becomes necessary to eliminate the dust nuisance and to preserve the surface.

The first step in the preparation of such a road is to restore it to a true cross-section and an even surface. This is done by repairing the ruts and depressions in the manner explained in Chapter VIII. After this has been done it is well to permit traffic on the road for a time to try out the repairs and further consolidate the patches, it being well known that a road is effectively consolidated by the vehicles using it even though the roller has been used for the repair work.

The next step is to clean the surface of the accumulation of stone dust, clay and other detritus. This is a troublesome task, especially on the older roads. The clay is usually caked on the surface and has been forced down into the interstices between the stones. If soft stone has been used for the road there will be an excess of dust to deal with. Sometimes the larger pieces of

stone have been badly fractured by the constant pounding of wheels and although the stone retains its form due to being confined in the road, it has become chalky. When this condition is encountered, proper cleaning becomes difficult if not impossible.

The road is first swept with a power broom, and mud or other material that has become caked on the surface is loosened with picks or shovels between trips with the broom. Material lodged in slight depressions is swept off with hand brooms. If the road were very dusty it may be necessary to flush it with water to remove the fine film not easily swept off. Every precaution must be taken to insure that the road metal is entirely free from dust because the bituminous surface will not adhere if any dust is left. If it is found impossible to secure a clean surface, the

Fig. 71.—Oiled macadam road.

attempt to place the bituminous carpet should be abandoned because it cannot be successfully accomplished.

When the surface is properly cleaned, the bituminous material is spread and covered in the manner already described for new macadam or gravel roads.

The cost of the surfacing is the same as for new roads but the cost of repairing and cleaning will vary widely as will be readily understood.

Bituminous carpets on gravel roads have never been very satisfactory and it is questionable practice to employ other than very fluid oils or tars for the purpose. It seems impossible to carry out the construction in any manner that will insure the resulting surface against peeling off.

Bituminous Carpets on Concrete Roads.—The bituminous carpet is applied to concrete roads and pavements for the reasons that have been mentioned in connection with gravel and macadam roads, except that there is no tendency for a concrete road to ravel under motor traffic. In addition to those reasons two others are of moment. Concrete roads have a tendency to crack in an erratic manner and if the crack is unprotected the concrete breaks down along it and the deterioration that follows is difficult to repair. It is common practice to fill the crack and cover the surface along both sides of it with a bituminous material. Covering the entire surface obviates the necessity for constant watchfulness in repairing cracks.

On account of the hardness of the concrete pavement it suffers somewhat from abrasion of steel-tired vehicles and eventually a slight tendency for the smaller pieces of the aggregate to break out is observed. A bituminous coating effectually prevents any considerable deterioration from this cause.

The concrete surface is cleaned by sweeping and washing so that every vestige of dust has been removed and the bituminous material is applied and covered with chips just as described for gravel and macadam surfaces.

The resulting surface is similar in every respect to the bituminous carpets already described.

No little difficulty is encountered in securing a material suitable for this work and the tendency for the carpet to peel off the concrete has never been entirely overcome. Bituminous materials suitable for this purpose are described in Chapters IX and XIII. It has been established, however, that with a suitable bituminous material and good workmanship such a carpet can be applied successfully. It will last for 2 or 3 years on fairly heavily traveled streets or roads. The cost of application, including the cleaning, ranges from 4 to 6 cts. per square yard of surface. The application should never be made until the concrete has been under traffic long enough to wear off the mortar film from the surface if any exists.

OHIO EXPERIENCE IN THE USE OF ROAD OILS[1]

Poor results in the use of oil treatments frequently come from the fact that the surface had not been previously cleaned in

[1] From *Bulletin* No. 27, Ohio State Highway Department.

a proper manner. If possible, the surface should be swept with horse sweepers, and afterward with hand brooms, so as to remove the dust from between the stones to a depth of from ¼ to ¾ in. The heavier the grade of oil used, the more important it is to have a clean surface on which to apply it. The surface should be dry and the warmer the air temperature the better.

There has been considerable discussion during the past year concerning sprinkling of the stone with water before applying the bitumens, it being claimed by some that better results may be obtained by first lightly sprinkling the stone with water before applying the bitumen; this information is likely to be misleading for it is believed that it is not the presence of water that might cause the better results, but the effect the water has in cleaning the dust which gives a better adhesion of the oil.

Hence, we would conclude that if sprinkling with water before applying the oil is done, it should be only on hot, dry days, and then sufficient time be given after the sprinkling for the water to practically all evaporate before the oil is applied. Therefore we are still warranted in saying that bitumens should be applied only to dry, warm surfaces. During June, July and August is the best time of the year to apply such materials to the road. (Note that this applies to Ohio.)

The amount of oil that should be applied to the road at any one time will depend upon the condition of the road surface, the quality of the oil used, and the nature of the traffic. In general, it may be said that a couple of light applications during the year will give better results than a single heavy application of the same amount of oil. For the lighter oils on a comparatively smooth surface, an application of not to exceed ⅛ gal. per square yard may be all that should be applied at one time while on a rough, pitted surface (with the binder swept from the top surface of the road to a depth of from ¼ to ¾ in.) as much as ¾ gal. per square yard of the heavier oils might give more satisfactory results.

The aim should be to put on just sufficient oil (and screenings) to form a thin mat over the surface of the road. This mat should not be of any appreciable depth over the surface of the larger stones, but sufficient to well seal up the voids between them. This will hold the binder in the stones and make the road surface water-tight.

A medium heavy cold oil will cost from 4½ to 6 cts. per gallon

delivered in tank cars. The cost of applying the cold oil varies from ½ to 1 ct. per gallon.

CARPET COATS ON CONCRETE IN CALIFORNIA[1]

A shortage of funds lead the California commission to seek a type of road cheaper in first cost, notwithstanding a consequential higher maintenance expenditure during the early years of its existence and the type called "concrete base with bituminous top" was adopted rather generally.

In this method of construction, the base is the same as if the 1½- to 2-in. covering were to be applied, but instead a thin coating of asphatlic oil of special quality is put on to the concrete by spraying machines at the rate of about ½ gal. to the square yard. Clean stone screening or coarse sand are then added in sufficient quantity to absorb the oil. The process requires much care in the selection of the materials used and in their manipulation, but the result is a bituminized coating about ⅜ in. thick. The cost of such surface work ranges from 5 to 10 cts. per square yard, or $600 to $1,200 per mile, roughly, for a 20-ft. pavement, depending on the cost of materials and local conditions. This means that more than 90 per cent. of the cost of the work on the road goes into grading, culvert work and the concrete base, all of which may be considered as practically permanent, and the remainder into the thin wearing surface.

Such a wearing surface should last from 2 to 4 years before it requires renewal, which renewal should cost considerably less than the original application. This thin surface is best adapted to rubber-tired vehicles, but it wears well under a considerable volume of mixed traffic consisting of both rubber- and iron-tired vehicles. I would have no hesitancy in recommending the thin road surface for a road covering as many as from 500 to 600 vehicles a day, provided a considerable portion of the vehicles are rubber-tired.

[1] A. B. Fletcher, State Engineer of Cal. in "California Highways".

CHAPTER XV

PENETRATION AND MIXED MACADAM ROADS AND PAVEMENTS

PENETRATION MACADAM

Bituminous macadam may be constructed by the penetration method with any of the kinds of stone that are used for the ordinary macadam. The methods of construction vary slightly in detail depending upon the character and size of the stone used, but the distinguishing characteristic is that the binder is poured onto the surface of the layer of stone and is expected to penetrate sufficiently to hold the surface together.

Sizes and Kinds of Stone.—Certain general principles governing the size of stone to use have been discussed in connection with water-bound macadam roads and these apply to penetration macadam as well, and the sizes commonly employed are summarized as follows:

A. Hard stone ranging in size from about 1½ in. down to ½ in. Chips from the same kind of stone and ranging from ½ in. down but with the dust removed.
B. Medium stone ranging in size from about 2½ in. down to 1 in. Chips from the above, screened through a ¾-in. screen and with the ¼-in. and finer removed.
C. Crusher-run stone of either hard or medium grade but containing no material passing ¼-in. screen.
D. Stone of either of the above grades but screened to a fairly uniform size such as 2½ in. to 1½ in., or 1½ in. to 1 in.
E. When chips of suitable hardness cannot be obtained, pebbles screened from hard gravel may be substituted. The size ranges from ½ in. down to ⅛ in.

It will be apparent that when rolled, class A stone will give a surface having smaller openings for the bituminous material to penetrate than will class B stone and that class C stone will produce a surface with smaller voids than either class A or B. It will also be seen that class D stone will produce a more porous surface than either class A or B or C.

It is therefore desirable to apply the bituminous binder to class C stone before any rolling is done and without spreading any chips prior to the application of the binder. Class A stone is rolled but no chips are spread before the binder is poured. Class B or D stone is rolled and the voids partially filled with chips before any binder is poured. Where class E material is used it is substituted for chips and is handled in the same manner as chips.

Bituminous Binders.—Both tar and asphaltic binders are used for the penetration macadam and the general characteristics have been discussed in Chapter XIII.

Foundation.—The stability of the bituminous macadam constructed by the penetration method depends largely upon the

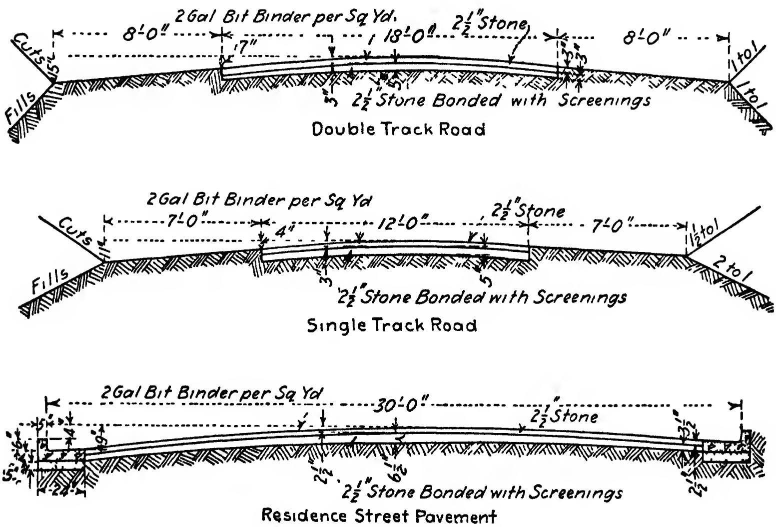


FIG. 72.—Cross-sections for penetration macadam.

kind of foundation provided and it is usually placed on top of either a Telford foundation or a broken-stone foundation which is bonded with screenings exactly as the surface of the water-bound macadam would be. Especial emphasis is placed upon the necessity of having the foundation true to shape. Its thickness will vary somewhat with the character of the earth subgrade. On good soils a foundation course 6 in. thick at the middle and 4 in. at the edge is not uncommon. Sometimes the base course is made a uniform thickness of 5 or 6 in. Fig. 72 shows typical cross-sections of penetration macadam roads and pavements.

The upper course of the surface is usually made of uniform thickness and seldom is less than 2 in. or more than 3 in. thick, depending primarily upon the size of stone used. If the 1½-in. size is used, the upper course would ordinarily be about 2 in. thick. If 2½-in. stone were used the layer would ordinarily be about 3 in. thick.

Wearing Course.—After the foundation course has been completed, the stone for the upper course is spread to the required thickness. Whether or not it shall be rolled before the bituminous material is poured into it depends upon the size of the stone and the texture of the surface. If the surface appears to be fairly well filled with fine material as would be the case with class C stone, it would be so dense when rolled that the bituminous binder could not penetrate into it. Therefore with such stone it is best to spread the bituminous binder before the surface is rolled.

Rolling.—It is desirable to have as great mechanical stability in the upper course as can be obtained and therefore it is better practice to use a coarser stone and roll the layer before the bituminous material is spread. If the stone has been rolled until the surface is closely knit together there will be little danger of the finished road becoming rutted or uneven and the bituminous binder will hold the chips in place and thus maintain a close-knit texture in the surface.

Examination of the surface after it has been rolled will show it to be made up of angular pieces of stone closely packed together between which are voids of varying size, depending upon the size of the stone and the thoroughness of the rolling. If the voids are large they must be partially filled with chips to prevent the bituminous binder from penetrating too deeply into the layer. Usually with stone of classes B and D the application of chips at this stage of the construction is advisable, but with class A stone the texture will be close enough without the chips.

When chips are used they are spread thinly over the surface from piles alongside and are brushed into the openings in the surface, any excess being brushed off at the edges. Care and persistence are necessary to secure an even texture in the surface and it can only be obtained if the chips are carefully spread and properly brushed into the surface.

The chips used must be of tough stone, otherwise they will

grind up rapidly under traffic because of their small size. If no hard, tough chips are available, clean screened gravel of the proper size may be substituted.

Applying Bituminous Binder.—The bituminous material is spread at a temperature that will insure its being fluid which may be anywhere from 250°F. to 450°F. depending upon the kind of material used. It may be spread by means of hand pouring cans, but this method is likely to result in a somewhat uneven distribution of the material.

The gravity type of distributing wagon is often used but it is also open to objection because of the variation in flow as the tank empties. The pressure distributing wagon is best from all standpoints and is coming to be the standard apparatus for this class of construction.

The quantity of bituminous material used for the first application varies from 1 gal. to 1½ gal. per square yard of surface. It is desirable to secure a penetration of about 1 in. and to coat all of the stones that show at the surface. Here again care must be exercised to secure uniformity.

After the first spreading of the binder, the surface is covered with chips which are brushed into the remaining voids in the surface and rolled lightly. The second application of binder then follows, the amount used being about ¾ gal. per square yard of surface. It is covered with chips and rolled. In some instances a third application of about ½ gal. of binder is used which is covered with coarse sand or chips and rolled.

Characteristics.[1]—The results of the experience so far gained with this type of construction seem to show:

First.—The necessity of providing as stable a foundation course as possible, and that probably the best method would be to lay the first course of the road as water-bound macadam, applying the bituminous top about 3 in. thick the following season when the foundation course has become thoroughly compacted.

Second.—The necessity for using durable stone in the bituminous top. Where limestone alone is available, the chips used for filling the voids and dressing the surface of the bituminous layers as they are applied should be trap, granite, or washed gravel and torpedo sand. Where the rock of which the road is made is tough and hard, rock chips could be used.

[1] See Fourth Report of Illinois Highway Commission.

Third.—It is necessary that the bituminous binder be spread so as to present as uniform a surface as possible. This may not necessarily mean the uniform distribution of the binder since the texture of the surface itself may not be quite uniform. Therefore, the more finely divided the form in which the binder can be applied, the better the control of its distribution. The form of the application whereby the material is spread by a jet of steam has given excellent results (see Fig. 73).

Fourth.—Too much binder should not be used as it will result in a less stable wearing course than if only sufficient binder is used to coat the stone and chips.

Fifth.—It is essential that the surface of the road have very close texture and usually this cannot be secured in less than three applications except by using an excessive amount of binder. The most economical and durable results can be secured when the binder is put on in three applications.

Sixth.—The bitumens which do not possess some ductility at freezing temperatures are usually not satisfactory.

Seventh.—It is important that bitumens be applied at high temperatures, and if possible, during hot weather, as some unsatisfactory results obtained can be attributed to the cold weather prevailing at the time of construction.

Eighth.—The roads constructed with tar binder under ordinary traffic conditions seem to require a paint coat at the end of the second, or at the furthest, during the third season. By this time the tar near the surface of the road seems to have lost most of its adhesive qualities. Those constructed with asphaltic binders seem to require the same treatment during the fourth year.

Ninth.—The size of stone in the bituminous layer should range from 2½ in. to ¾ in. where limestone is used. When trap rock or other equally hard material is available, stone should not exceed 1½ in. in size; the chips for filling the stones not to exceed 1 in. in size and the grit for the top dressing should not exceed ¼ in. in size, and all of the material should be free from dust.

Tenth.—Experience indicates that this form of construction is adapted to moderate traffic roads, that is, where there is no large amount of extra-heavy hauling. Where the traffic is composed of automobiles and farm loads of not to exceed 2 tons, this form of construction will prove satisfactory, although not as durable as some more expensive roads. Where traffic consists

of heavier loads such as wholesale trucks, coal trucks and loads reaching to 5 and 6 tons, it is believed this form of construction is not at all suitable.

It presents a pleasing appearance and is well adapted to horse-drawn traffic as well as automobile traffic, but requires close attention to maintenance, and there is some evidence that during warm weather when the bitumen is least stable there is a tendency for the surface to creep and undulations develop.

The cost of this form of construction over that of first-class water-bound macadam is approximately 20 cts. per square yard, but there has not been had sufficient experience to determine definitely the maintenance cost and its final economy. The construction requires the utmost care in every detail, and this fact has not always been appreciated, with the result that much poor work has been done.

Where attention is given to the construction, and suitable materials are used, there is no difficulty in duplicating results.

Bituminous macadam is of doubtful value on those sections of road so situated that considerable quantities of mud will be tracked on them from adjoining earth roads.

MACHINERY AND APPLIANCES USED FOR BITUMINOUS MACADAM CONSTRUCTION

Pouring Cans.—Bituminous materials are sometimes spread on road surfaces by means of hand pouring cans which are much like a garden watering pot except that the spout is larger and the nozzle is a slot instead of a perforated disc. In some types of cans the slot is horizontal and in others vertical, the latter being preferable. It is also an advantage if the width of the slot is adjustable so as to help control the rate of flow of material.

Gravity Distributing Wagons.—Wagons of this kind are used for spreading bituminous materials on road surfaces either for penetration construction, carpeting or dust laying. As the name indicates, the bituminous material flows from the tank by gravity and is consequently somewhat variable in amount depending upon the height of material in the tank. The distributing devices or nozzles are of many types but in the essential consist of a pipe supported about 1 ft. above the road surface and having circular openings or slots for the material to flow through. The pipe is suspended from the rear of the tank and

is slightly longer than the tread of the wagon. A control valve is attached to the delivery pipe in most wagons of this kind and many of them are equipped with fire boxes so that the contents of the wagon may be heated.

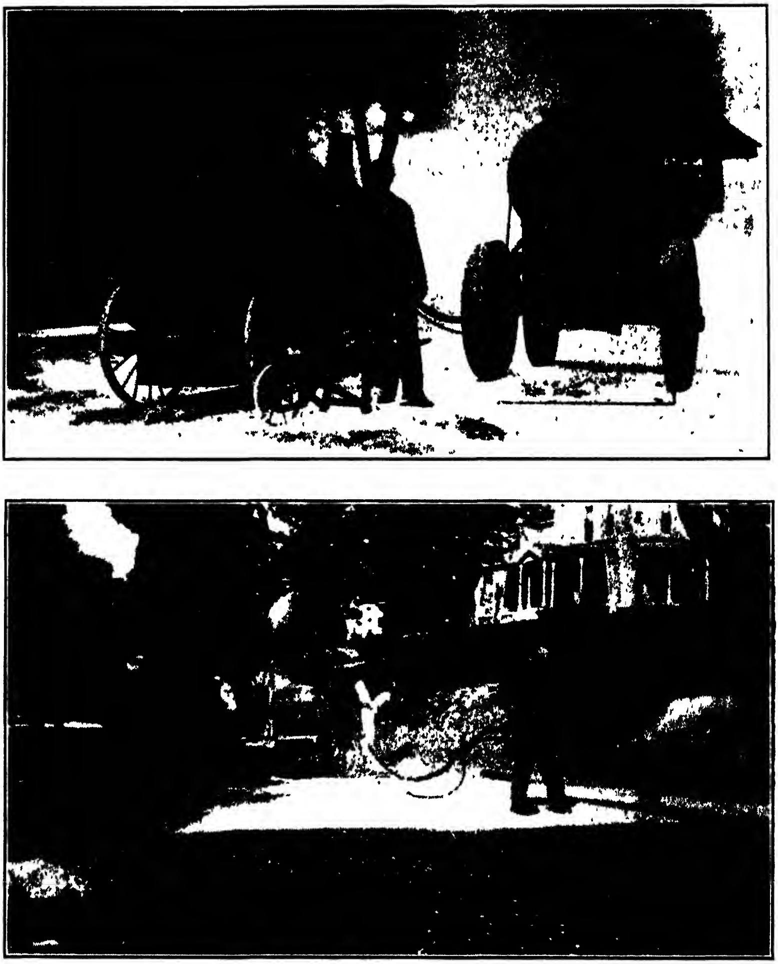


FIG. 73.—Distributing outfit utilizing steam spray.

Pressure Distributing Wagons with Multiple Spray.—In order to give better control of the quantity of material being distributed and to force it into the minute openings in the road surface, pressure distributors have come into extensive use. In general design they are similar to the gravity distributor except

that air or steam pressure is applied to tank so as to force the material out of the nozzles at a high velocity. The distributing devices usually consist of a series of small nozzles screwed into a pipe which is suspended across the rear of the wagon about 6 in. from the road surface. In some machines of this type the pressure is obtained by pumping the hot material out of the tank and forcing it through the nozzles. The horse-drawn distributors usually have a tank capacity of about 500 gal.

In recent years many elaborate motor-driven distributors have been constructed and these have a wide range of capacities. For surfacing country roads the motor-truck type is very much to be preferred to the horse-drawn because of the saving in time effected in getting the material from the railroad siding to the road. The sprays are of many designs and the pressure is sometimes obtained by pumping the binder and sometimes by pumping air into the tank.

These motor distributors are well adapted to the purpose for which they are used. The quantity of the bituminous material that is used can be controlled within very narrow limits.

SINGLE-NOZZLE DISTRIBUTOR EMPLOYING A STEAM SPRAY

This type of distributor is shown in Fig. 73. The bituminous material is heated in the tank wagon or in an auxiliary kettle and drawn into the tank wagon by pumping the air out of the tank.

The hot binder is then applied to the road surface through a nozzle at the end of a length of flexible metal hose. The operator spreads the binder according to the needs of the surface.

At the orifice in the nozzle a jet of steam is introduced into the binder forcing it out in a finely divided spray and the quantity is varied by a valve in the supply pipe. This method is very satisfactory for macadam construction.

EXAMPLES OF GOOD PRACTICE

Maine[1]

Crushed Stone.—The crushed stone used in this work shall be newly broken, or uniform quality throughout and free from tailings, slaty and flat fragments, soft or disintegrated stone, dirt or other objectionable matter.

[1] Specifications, Maine Highway Department, 1915.

The following designations and sizes shall obtain:

Dust.—That portion of the product of the crusher which will pass through a screen having one-quarter ($\frac{1}{4}$) inch circular openings.

Chips.—That portion of the product of the crusher which will be retained on a screen having one-quarter ($\frac{1}{4}$) inch circular openings and will pass through a screen having one (1) inch circular openings.

No. 2 Stone.—That portion of the product of the crusher which will be retained on a screen having one (1) inch circular openings and will pass through a screen having circular openings not less than two (2) inches nor greater than two and one-quarter ($2\frac{1}{4}$) inches in diameter.

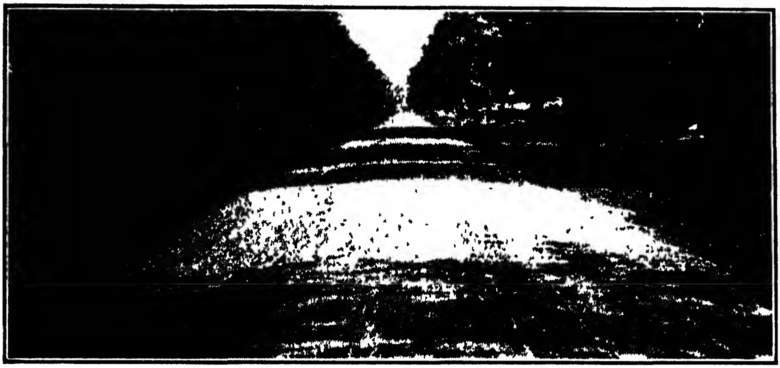


Fig. 74.—A penetration macadam road.

No. 1 Stone.—That portion of the product of the crusher which will be retained on a screen having circular openings not less than two (2) inches nor greater than two and one-quarter ($2\frac{1}{4}$) inches in diameter, and will pass through a screen having circular openings not less than three (3) inches nor greater than three and one-half ($3\frac{1}{2}$) inches in diameter. The stone shall be granite or trap.

Bottom Course.—The bottom course shall consist of a single layer of No. 1 stone, $3\frac{1}{2}$ in. in thickness when compacted, and shall be spread so that after being thoroughly compacted with a road roller of the macadam type, its surface will be parallel to and uniformly below the finished road surface by an amount equal to the thickness of the wearing course. Stone screenings or sharp sand shall be spread over this course. In no case, how-

ever, shall such an amount of screening or sand be used as to fill the bottom to within less than ½ in. of its surface.

In the event that any course of stone shall have become rutted or loosened by travel before the application of the next succeeding course, the contractor shall bring the said course of stone to its proper cross-section with such materials and in such manner as the engineer shall direct.

Second Course.—The second course shall consist of a layer of No. 2 stone evenly spread over the bottom course to a depth of 3 in., loose measurement. This course shall be dry-rolled until the fragments of stone are well keyed together and the surface conforms to the cross-section shown in the plans. In order to allow penetration of the hot bituminous binder applied in the manner hereinafter specified, the surface of this course shall be open and porous.

Bituminous Binder.—Sufficient and approved facilities for delivering and heating the binder shall be provided. It shall be maintained within a temperature range of 250°F. to 300°F. for tar products and 300°F. to 350°F. for fluxed native and oil-asphalt products.

First Application of Bituminous Binder.—The hot bituminous binder shall be uniformly distributed over the second course at the rate of 1½ gal. to the square yard, either by pouring pots or applied under pressure from a tank wagon equipped with hose and nozzle of a type approved by the engineer. Immediately after this application, clean stone chips shall be spread over the surface in sufficient quantities to just completely fill the surface voids, after which the course shall be thoroughly rolled. When rolling is completed, any surplus chips shall be swept from the surface. The bituminous binder shall be applied only during dry weather, and the stone of the second course must be dry and clean at the time of application.

Seal Coat.—A seal coat of hot bituminous material shall be uniformly distributed as above described, at the rate of one-half (½) to three-quarters (¾) of a gallon to the square yard. It shall be immediately covered with a layer of clean stone chips, in an amount sufficient to take up all excess bituminous material, and shall then be thoroughly rolled.

Weather.—No bituminous material shall be applied at any time when the air temperature is below 60°F. or when the air temperature within the preceding 24 hr. has been 35°F. or lower.

Illinois[1]

As is well known, the stability or strength of a macadam-road surface to resist the action of traffic depends entirely on the mechanical locking together of the pieces of stone making up the road surface, and until this is accomplished the road surface has no cohesion. The more perfect this keying or locking together of the pieces of the stone, the more rigidity; therefore, the object of any binder, whether of stone dust or of a bituminous character, is to hold the pieces of stone firmly in position after they have become well keyed and locked together. In many pieces of road that have been constructed, and in some forms of construction that have been proposed, this essential principle of the macadam construction seems to have been ignored. It would appear that if bituminous macadam is to be successful it is necessary in its construction to follow what has been learned by long experience, and that is to have the macadam itself firmly locked and keyed together and the stability of the road thereby assured before any binder has been applied.

The next step, therefore, after the base course has been prepared, as has already been described, is to spread the stone for the wearing layer. The stone for this layer, if limestone, should be composed of pieces 2½ in. in size and graded from this downward. If a 3-in. layer is to be made when consolidated, which is as thick as this layer need be, the stone should be spread to a thickness of 3½ in. and thoroughly raked or harrowed so as to bring the larger pieces to the surface in order that the surface may be composed in the first instance of as nearly uniform sized material and to give as great compactness as possible after it is rolled. As soon as spread uniformly and harrowed, the surface is to be rolled until it is thoroughly tightened. It may be found that there will be places where the stones do not lock together firmly; on such places a small amount of stone should be spread, just sufficient to fill the interstices, and then rolled. The effect of this rolling is to force the pieces of stone into the interstices, thus keying the whole surface until tight. It is important that great care be taken in rolling this upper layer that it be thoroughly tightened. When this has been accomplished, there will still remain interstices of appreciable size which should be filled with stone chips. These chips

[1] From the Fourth Report of Illinois Highway Commission.

should be preferably of some harder material than limestone, and it is often possible to secure screened gravel that will prove excellent for this purpose. The size of the chips should vary from ¾ to ⅜ in., and they should be spread over the surface of the upper course in just sufficient quantity to fill the interstices.

A good method to insure this being done is first to shovel the chips on by hand, throwing each shovelful so as to cover as much area as possible; then follow with hand brooms, sweeping ahead the surplus pieces and allowing all the interstices to become thoroughly filled. When this is done, the road is ready for the bituminous binder, as no rolling should be attempted after the chips have been spread and before the binder is applied. If the chips are rolled before the binder is applied, the effect would be merely to allow them to set in between the stones which have already been well compacted and tend to loosen the surface rather than tighten it. It is important that after the surface has been thoroughly keyed and the chips spread, no rolling be done until after the bituminous binder has been applied.

The amount of the binder to be applied should be as little as is necessary to secure a thorough coating for all the exposed surfaces of the stone. This usually requires from ¾ gal. to 1 gal. per square yard. When this amount has been applied, the surface should again be dressed with the stone chips or screened gravel so as to make practically one layer of the chips evenly distributed over the entire surface of the road. This gravel had better be applied as soon as possible after the binder has been spread, if practicable following immediately behind the spreader. It may be spread somewhat in excess and swept ahead with a broom. It is important that the gravel be clean and have as little dust adhering to it as possible.

After the gravel has been spread the second time more binder is applied which should be sufficient thoroughly to cover all of the gravel. This usually requires ½ to ¾ gal. per square yard. Coarse sand, if available, should then be spread upon the road, or finely screened gravel may be used. After the surface has been covered with the fine gravel graded from ⅜ in. to ⅛ in., a seal coat of binder, using ½ gal. per square yard, is applied. The surface is then covered with the fine gravel and rolled. The roller should be provided with pipes with small orifices an inch or two apart so as to keep the wheels of the roller wet while rolling. If this is done, there will be no difficulty whatever with

the binder sticking to the roller wheels. The rolling should continue until the surface is seen to be well set and compacted. It will then perhaps be found that there are some spots needing further treatment to bring them to a uniform appearance with the remainder of the road, in which case, if there be any dust, it should be swept away, fine gravel and binder applied and the whole rolled to give a uniform surface It is probable that quite as good or better results can be obtained, after the road has been sanded and rolled, to throw it open and let the traffic develop any places in the road that need further attention.

This form of construction, it will be seen, gives a road which has the strength and rigidity of the ordinary macadam, with a water-tight covering of bituminous compound holding the surface of the road intact against the action of the motor traffic or dislodgment by the mud that adheres to the wagon wheels. So long as the waterproof covering can be maintained, the road should be in perfect condition. The gravel in the surface furnishes the resistance to abrasion. This is greatly helped by the binder, if of proper quality, which will tend to keep the particles covered or imbedded as fast as they may become loosened or broken by the traffic. When in the course of time the surface has become sufficiently worn to expose the stone making up the wearing course, it can be renewed by thoroughly cleaning the road, putting on a light application of the binder and renewing the fine gravel.

MASSACHUSETTS[1]

Size of Stone Important.—The size of stone in the top course is regarded as a matter of vital importance in the construction of a road by the penetration method. The Massachusetts Highway Commission employs stone ranging from 1½ to 2½ in. in size. The large stone, it has been found, binds together more firmly than smaller stone and consequently is subject to less wear from the grinding of one fragment against another in the body of the pavement due to the passage of vehicles over the road surface. Small-sized stone tends to loosen quickly under this grinding action, and if the bituminous binder loses its life and is not speedily renewed, the road quickly goes to pieces. With stone of large size no such result may be expected. It

[1] Abstracted from *Engineering Record,* May 15, 1915.

is true that with the larger stone the voids are greater and consequently a larger amount of bitumen must be used to fill them, the excess being generally about 3/8 gal. per inch depth of top course for the large-stone type of construction. Thus a small stone pavement with tar as a binder and a 2-in. top course would cost about 6 cts. less a square yard than the large-stone type of pavement. In spite of this slight increase in cost the large stone is believed to be amply justified.

With small stone it is practically impossible to secure any great depth of penetration with a single application of bitumen. It becomes necessary, therefore, if small sized stone is used, to build the top course in several layers and apply the binder to each—obviously a more costly procedure than the distribution of the binder in a single operation, as is feasible when large stone is used.

As to the quality of the stone in the top course, this depends to a large extent upon the character of the traffic to be handled. For very heavy teaming the Massachusetts Commission believes that the best results can be secured with trap rock and a high-grade asphalt. With a tar binder, instead of asphalt, a softer grade of rock is permissible, for the tars deteriorate more quickly than do the asphalts. Asphalts are preferred because of their greater cementing value and their higher resistance to disintegration by moisture.

Preparation of Subgrade.—The first step in the construction of a road by the penetration method, according to the Massachusetts standards, is the provision of adequate drainage. In loamy or clayey soils it is common to put in a subbase of gravel 1 ft. thick or a Telford base from 1 ft. to 18 in. thick. The Telford base may even be underlaid by a layer of gravel not exceeding 8 in. and the interstices at the tops of the stone filled in with smaller-sized materials. In springy ground stone drains with open-jointed sewer pipe are insisted upon. These are located at the sides of the road when the grade is level and on the uphill sides if along a hill. It is important that this subbase be thoroughly compacted and it is therefore rolled with a 10-ton steam roller until no settlement is discernible.

Upon this base course is spread a layer of broken stone from 1/2 to 3 in. in size which is compacted to a depth of 4 in. after rolling. This forms the bottom course for the penetration roads. There should not be too much fine stone in this layer. After

it has been thoroughly rolled the pieces in the bottom course are partly bound by filling the interstices with smaller-sized stone, sand, screenings, or stone dust. For this bottom course the size of the stone is not of particular importance. It should, however, not be bound too thoroughly and may or may not be sprinkled, depending upon the nature of the material. It must be rolled until thoroughly compacted. This is most important, for if the base is not rigid depressions will develop in the wearing surface. The bottom course is placed generally in several spreadings and varies somewhat, due to the nature of the foundations and the character of traffic. If placed on an old macadam roadway 2 in. of new stone may be sufficient; for a new roadway to carry heavy traffic it may be necessary to use 5 in. of stone in the bottom course.

Top Course.—The methods outlined for the base apply to all types of bituminous macadam construction. It is next in order to describe the top or wearing course for heavy traffic conditions.

Upon the base prepared, according to the method outlined, the best results have been secured by spreading trap rock varying in size from 1½ to 2½ in. to a depth of 2 in. after rolling. This 2-in. thickness for the wearing course is sufficient for ordinary traffic, but for exceedingly heavy traffic the top course might be made 3 in. and placed in two layers. The stone is carefully spread from dumping boards, thoroughly rolled and all depressions filled. No sprinkling is allowed on the top course.

When it shows no movement under the steam roller the top course is ready to receive the bituminous binder. While good results have been secured by hand-pouring, the best work has been done with pressure distributors using air for pressure.

Preference as to Binders.—The preference for binders on penetration work is as follows: First, lake asphalt; second, oil asphalt; third, tar. Tars, it is stated, have stood up under traffic which the oil asphalts could not bear, but the disadvantage of the tar is that it does not retain its life as long as the oil asphalt.

If a natural asphalt is used it must be heated at least to a temperature of 300°F.—usually about 350°—and applied under a pressure of 60 lb. per square inch. The rule of the Massachusetts Highway Commission is to use about 1 gal. of binder to each inch of thickness of the top course. The greatest care is necessary to apply the binder uniformly. With the 2-in. top course used on most of the roads the application of binder has amounted

to about $1\frac{3}{4}$ gal. per square yard of road surface. When the binder has been applied the surface of the roadway is immediately covered with a light layer of pea stone, just thick enough to prevent the roller from picking up the surface. The pea stone is broomed and used to fill the voids and is then thoroughly rolled. For this operation the best results are secured with a heavy roller from 15 to 18 tons. After rolling, the surplus stone is swept off and a second application of binder made to form a seal coat. The seal coat is applied at the rate of about $\frac{1}{2}$ gal. per square yard. The road surface is again covered with pea stone and thoroughly rolled. This completed the operation of building a pavement by the penetration method.

MIXED BITUMINOUS MACADAM

Mixed bituminous macadam is a road surface consisting of crusher-run stone or of gravel cemented together by means of a bituminous binder. The materials are hot-mixed and the mineral aggregate is selected and graded in such a way as to secure reasonable density in the surface. In appearance the finished mixed macadam resembles the penetration macadam very closely.

Stone for Mixed Macadam.—Crusher-run stone with the dust removed or mixtures of stone and sand are employed for the mixed macadam. The principles that are observed in selecting the proper size of stone for the penetration macadam are also applied to the selection of stone for the mixed macadam. If medium or soft stone is to be used a larger size is required than if a hard and tough stone is available. Quite generally the crusher-run stone with the dust removed is employed. It is apparent that the voids in the aggregate will be a considerable per cent. and the essential difference between the hot-mixed macadam and the asphaltic concrete is in the care with which the aggregate is graded for the latter type of surface.

It will be recalled that in the discussion of penetration macadam, attention was called to the use of crusher-run stone and the difficulties of securing penetration of the bituminous material. The mixed macadam was developed to overcome that difficulty and yet secure the advantages of the better grading obtained by the use of crusher-run stone instead of screened stone.

Foundation.—The mixed macadam is placed on top of an old water-bound macadam or gravel road or upon a newly constructed base of water-bound macadam or gravel. The necessity for a rigid foundation course has been frequently referred to in connection with the other types of construction and is equally important for the mixed macadam. If an old macadam or gravel road is used for a foundation it must be brought to a true surface parallel to that prescribed for the finished road and enough below it to permit placing a uniform surface layer of the requisite thickness. A foundation course of lean concrete is sometimes used

Fig. 75.—Portable melting tank for bituminous materials.

but this type of base is not common. When used the mixture is usually 1–3–6 or leaner.

When a new macadam base is constructed for this surface it is built exactly in the same manner as the base for the penetration macadam.

The bituminous cement and the stone or gravel are heated separately and then mixed either by hand or in a hot mixer of the type resembling the concrete mixer. The amount of binder used is from 15 to 20 gal. per cubic yard of stone.

The hand-mixing method has little to recommend it except that but small expense is entailed for equipment which is a factor to consider on small work.

The portable type of hot mixer which is drawn along the road

as work progresses is frequently employed and is satisfactory although somewhat limited in capacity. Fig. 76 shows such an outfit in operation.

The permanent or semi-permanent plant located near the stone supply is also frequently employed and is the most economical in operation. The distance that the mixture can be hauled must be considered and this will usually necessitate the use of the portable plant for rural highway surfacing.

The mixture is prepared at a temperature of about 200°F. and must be spread at a temperature of not less than 150°F. These temperatures vary somewhat with the kind of bituminous binder used as would be expected.

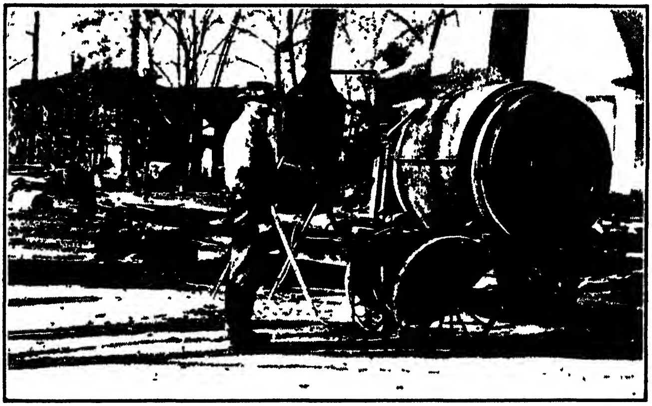


Fig. 76.—Portable mixer for macadam construction.

The mixture is conveyed to the road in dump-bottom wagons or in motor trucks and is dumped on metal shoveling platforms from which it is shoveled into place in the road, and raked to the thickness necessary to provide for compression during rolling.

The rolling is done with a tandem roller weighing about 6 tons, and is continued until the surface is thoroughly compacted. The roller moves parallel to the edge of the road as in rolling water-bound macadam, and the operation proceeds in much the same way.

After the surface has been properly compacted it is covered with a thin coating of the bituminous material applied as a seal coat. The quantity required for the seal coat varies from ⅓ to ½ gal. per square yard of surface and the material is spread over the surface with a fiber broom or with a squeegee.

The surface is finally covered with a light dressing of stone chips ¾ in. in size and free of dust, or of pea-size gravel and is rolled just enough to bed the dressing in the seal coat.

The mixed macadam surface varies in cost between 60 cts. and $1 per square yard, exclusive of the base course.

Its characteristics are in general similar to those of penetration macadam except that it is more uniform in texture and consequently more durable. It is not widely used, but has passed the experimental stage and its construction is well standardized.

SPECIAL APPLIANCES USED

Sand and Stone Heaters.—These usually consist of a furnace around which a metal hopper is built. The material to be

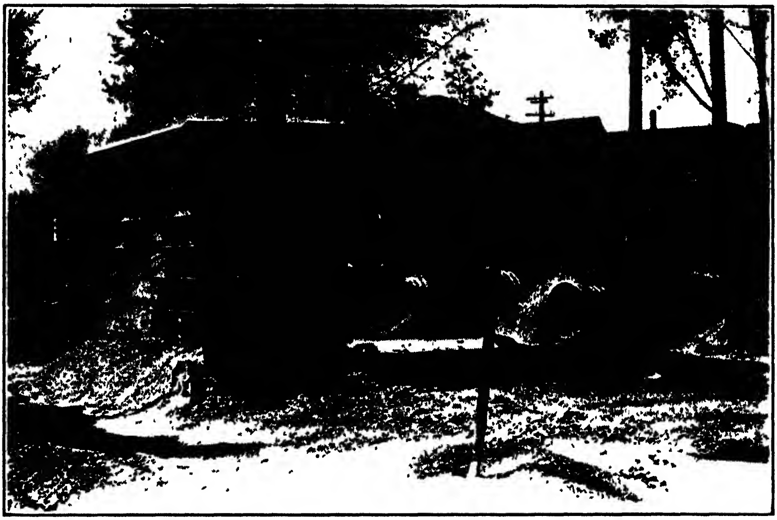


Fig. 77.—Portable heater for stone and improvised sand heaters.

heated is thrown into the top of the hopper and when heated is shoveled out at the bottom. Sometimes the heater consists merely of metal pipe about 2 ft. in diameter which is laid on the ground and covered with the sand or stone. A fire is built inside the pipe and as the material becomes hot enough for use it is shoveled away and a new supply placed around the pipes.

Melting Tanks.—Melting tanks are made in a great variety of shapes and capacities but all are designed on the same general

principle. The outfit consists of a comparatively large furnace over which is mounted a tank for the material. The furnace will burn either coal or wood. The capacity varies from a 50-gal. kettle to a 500-gal. tank. In the larger sizes a barrel rack is sometimes mounted above the kettle and enclosed in a sheet-iron case. The kettle is partly filled with the cold material and the rack is filled with barrels open end down. The heat from the kettle gradually softens the material in the barrels so that it will flow down into the kettle to replace the hot material as it is drawn off. The tanks are mounted on wheels so as to be easily portable.

Mixers.—The portable type of hot mixer is used. In design it is very similar to the concrete mixer except that the drum is jacketed leaving a space between the mixer drum and the jacket through which the hot gases from the furnace are forced by means of a fan. The materials are heated before they are placed in the mixer and it is only necessary to have the drum hot enough to maintain the temperature.

EXAMPLES OF GOOD PRACTICE

Massachusetts[1]

The bituminous mixture shall be laid in one course and shall be after rolling two (2) inches in thickness.

The width shall be thirty (30) feet.

The broken stone shall be trap rock and shall vary in size from one-quarter (¼) inch to one and one-quarter (1¼) inches in their longest dimensions. All broken stone used shall be absolutely clean and free from adventitious matter.

When the broken stone has been heated to not less than 150°F. or more if the engineer so requires, it shall be mixed with the asphalt, by machines, which shall be approved by the engineer, and as the engineer may direct, until all particles of stone are covered with asphalt.

Sixteen (16) gallons of asphalt measured at temperature of the air shall be mixed with each cubic yard of stone.

Before mixing with the stone, the asphalt shall be carefully heated to not less than 350°F. and at that temperature shall be mixed with the stone. No asphalt shall be used after it has

[1] From specifications kindly furnished by Massachusetts Highway Commission.

been injured by overheating or burning. The contractor shall heat the asphalt in suitable kettles satisfactory to the engineer.

After being properly prepared as hereinbefore stated, the mixture shall be teamed to the road and spread before it has cooled to a temperature below 100°F.

The mixture shall be dumped on steel dumping platforms or shoveled directly from the cart into place. As the spreading is done rakes shall be used to obtain a uniform distribution of stones and an even surface before rolling.

The mixture, after being satisfactorily spread and raked, shall be at once rolled with a tandem roller, weighing not less than seven (7) tons, care being taken not to push the mixture out of place by the roller, but to roll so as to lay it down, compressed to a perfect cross-section, and true to line and grade. During very hot weather the rolling shall be postponed until cool enough to roll without pushing out of place and shape.

If any unevenness or depressions appear during or after rolling the bituminous mixture, suitable material (mixed), satisfactory to the engineer shall be added, and rolled in a manner to remove all such unevenness or depressions.

Immediately after the bituminous mixture is rolled to a firm surface and free from irregularities, a seal coat of Bermudez asphalt shall be so applied as to completely cover the surface, using one-third (1/3) of a gallon of asphalt per square yard of surface. It shall be carefully spread with "squeegees" or brooms.

Immediately after it has been spread it shall be covered with clean trap-rock pea stone and rolled until the pea stone is bonded with the asphalt of the seal coat.

No teaming or travel of any kind shall be allowed to pass over the new surface until 24 hr. have elapsed after the final rolling or until the surface has become sufficiently hardened to prevent injury by picking up or tracking.

No bituminous work shall be done during rainy weather nor when weather conditions as to temperature or otherwise are, in the opinion of the engineer, unfavorable to obtaining satisfactory results.

In order to provide for passing traffic during the progress of the work it will be necessary to construct only one-half of the width of the roadway at one time. The lower course of that portion of the roadway which shall first be laid shall be extended

two (2) feet beyond the center of the road or two (2) feet beyond the inside edge of the bituminous mixture so as to provide a firm base for the bituminous mixture, also to satisfactorily bond into the remaining portion of the bottom course when laid.

The bituminous mixture and sealing coat of that portion first laid shall lap over the line of the joint at the center of the roadway, so that when the second half is laid the first half can and shall be cut back to a uniform longitudinal line and perfect vertical section so as to obtain a perfect joint and cross-section.

From the time of commencement of laying the bituminous mixture during and until the time the final covering of pea stone is spread on the seal coat, the adjoining surface on any or all sides of the portion under construction shall be kept watered as directed by the engineer to prevent dust alighting on the bituminous surface.

GRAVEL AGGREGATE

Broken stone consisting of local stone or gravel stone shall be spread and rolled on the road bed, prepared as hereinbefore described, as follows:

The width of the broken stone and bituminous surfacing shall be eighteen (18) feet.

The lower course shall consist of stones varying in size from one-half (½) inch in the smallest dimensions to three (3) inches in the largest dimensions and shall be four (4) inches in depth at the center and sides after rolling.

It shall be understood that the crusher will be set up at the gravel pit and that all gravel run through the crusher shall be used, the finer material being used in the oil mixture, and if there is not sufficient stone in the gravel for the lower course, the other stone shall be obtained from the fields and crushed.

If there should be too much stone after allowing the one-half (½) inch stone for the lower course, the size of the smaller stone to be used in the lower course shall be increased, according to the directions of the engineer, and the half (½) inch or larger stone not exceeding one and one-half (1½) inches used in the bituminous mixture.

The lower course shall be shaped to a true section conforming to the proposed cross-section of the highway and thoroughly rolled.

Any depressions or irregularities which may occur shall be

filled with smaller stones as directed by the engineer, and again rolled until the surface is true and unyielding. The interstices in this course shall then be filled with clean, sharp sand, or stone screenings, and after being thoroughly rolled dry the sand or screenings shall be just below the top of the broken stone, as directed by the engineer, and no sand or screenings shall be left on top of the stones.

Upon the lower course shall be spread the bituminous mixture, which will form the wearing surface and shall consist of sand and gravel stone mixed with asphaltic oil; the sizes of sand and gravel stone, proportions of sand, gravel stone and oil, and the method of mixing and spreading to be as hereinafter described.

The bituminous surfacing shall be laid in one course and shall be two (2) inches in thickness after rolling. Sand of a quality satisfactory to the engineer shall consist of particles that will pass through a screen with meshes one-quarter (1/4) of an inch square, and be free from clay, loam and adventitious matter.

The gravel stones shall vary in size from one-quarter (1/4) inch to one and one-half (1 1/2) inches, and no stones larger than one and one-half (1 1/2) inches in their largest diameters shall be used. Screenings from the crusher may be used in the bituminous mixture.

Of the sand and gravel aggregate not more than 75 per cent. and not less than 15 per cent. shall consist of gravel stones of the size hereinbefore specified.

The proportions of sand shall vary according to the proportions of stone used.

When the sand and gravel stones have been heated to not less than 180°F., or more if so directed by the engineer, it shall be mixed with the oil by machines, which shall be approved by the engineer, and as the engineer may direct, until all particles of sand and gravel are covered with oil.

Before mixing, the stone and sand shall be heated separately and carefully measured to obtain the correct proportions of each.

Not less than fifteen (15) gallons, nor more than twenty (20) gallons, of the oil, as the engineer may direct, shall be mixed with each cubic yard of sand and gravel.

Before mixing with the sand and gravel, the oil shall be carefully heated to not less than 200°F. and at that or such higher temperature as the engineer may direct shall be mixed with the sand and gravel.

No oil shall be used after it has been injured by overheating or burning.

The contractor shall heat the oil in suitable kettles or by steam coils or in such manner as may be satisfactory to the engineer.

After being properly prepared as hereinbefore specified, the mixture shall be teamed to the road and spread before it has cooled to a temperature below 100°F.

The mixture shall be dumped on steel dumping platforms, or shoveled directly from the cart into place.

As the spreading is done, rakes shall be used to obtain a uniform distribution of the sand and gravel stone and to smooth the top surface before rolling.

The mixture, after being satisfactorily spread and raked, shall be at once rolled with a tandem roller weighing not less than seven (7) tons, care being taken not to push the mixture out of place, with the roller, but to roll so as to lay it down, compressed to the proper cross-section, and true to line and grade.

When necessary, in the opinion of the engineer, the rolling shall be postponed until cool enough to roll without pushing out of place and shape.

If at any time before the acceptance of the work any soft or imperfect places or spots shall develop in the surface, all such places shall be removed and replaced with new material and then rolled until the edges at which the new work connects with the old becomes invisible. All such removal and replacement of unsatisfactory surfacing shall be done at the expense of the contractor.

Rhode Island

Since 1906 the Rhode Island State Board of Public Roads has constructed a large amount of bituminous macadam by the cold-mixing method. Some features of the process are described as follows:

For the standard 14-ft. road, crushed stone which passed a 3-in. screen and was retained on a 1½-in. screen was first spread over the well-rolled subgrade to a depth of 4 in. after compression. This course was not filled with sand or stone screenings but was well rolled. Crude tar was very lightly sprinkled over this first course. Crushed stone of the same sizes was then mixed with crude tar in the proportion of 15 gal. of tar per cubic yard of stone. Mixing was carried out on a portable wooden mixing

platform near the point where the mixture was being spread. The mixture of stone and tar was spread over the first course of crushed stone to a depth of 2 in. after compression, and was well rolled, after which a covering of stone screenings was applied. The results secured on this first experimental section of bituminous macadam were remarkably successful, largely due to the stable, gravelly subsoil.

Seal Coat.—Subsequent experiments have proved the advisability of seal-coating. We attribute the marked success of the early work in spite of the absence of a seal coat largely to the character of the travel. The horse-drawn traffic is very light, and we believe that the blows of horses' shoes on the exposed surfaces of the soft stones would be destructive were it greater.

Precautions Needed.—It has been proved in our work that the utmost care in using the cold-mixing method is necessary. The crushed stone must be perfectly dry at the time of mixing and all stones must be perfectly covered with bitumen in order that good results may be secured. The matter of carrying out the rolling is also important in its effect on the results obtained. It is, of course, necessary to secure by rolling as compact a mass as possible, but we have found that considerable care must be exercised in regulating the time and amount of rolling. If the weather is cool at the time of construction, we frequently postpone the heavy rolling until midday, when the maximum warmth is experienced, although the initial rolling is done as soon after the mixture is laid as possible.

Character and Size of Stone.—The character and size of the crushed stone employed are also of importance. We have secured the best results, as far as stone is concerned, with our native rock, which is rather variable in character. As a rule, our native rock is softer than trap rock and breaks with a much more irregular fracture. There is more or less breaking by rolling, and this appears to be beneficial rather than otherwise in that a denser pavement is secured. We feel that if trap rock were employed smaller sizes would be necessary than with a softer stone, unless there is a certainty of securing a perfect crusher-run from 1½ in. to ¼ in. or less.

WEATHER CONDITIONS

Weather conditions influence the results considerably. Roads built late in the fall, just before freezing sets in, are not likely to

be as satisfactory as those built in midsummer, even though the temperature at the time of construction is not low. It seems to be a decided advantage to roads built by this method of construction to have a comparatively long period of warm weather immediately after construction in order that the surface may become freed from the top covering of stone screenings and well smoothed out before snow and ice appear. In Rhode Island we consider the season most favorable to this type of construction to be between the middle of May and the middle of October.

On the whole the cold-mixing method of constructing bituminous macadam as practised in Rhode Island appears to be an economical pavement for motor-vehicle traffic. It does not appear to the writer as suitable for heavy horse-drawn traffic or for a heavy mixed traffic. The travel on several of the trunk lines in Rhode Island consists of motor vehicles to the extent of more than 90 per cent., and it is on these roads that we expect in the future to confine our bituminous macadam roads built by the cold-mixing method. Through large villages where the percentage of horse-drawn traffic is large we expect to take up a stronger method of construction.

CHAPTER XVI

SHEET-ASPHALT AND ASPHALTIC CONCRETE SURFACES

I. SHEET-ASPHALT PAVEMENTS

The sheet-asphalt pavement consists of three layers, the Portland cement concrete or other base, the binder course, and the wearing course. It receives its name from the fact that the wearing course consists of a layer or sheet of a mastic composed of fine mineral aggregate and asphalt cement.

Earth Foundation.—All of the principles relating to drainage that have been discussed heretofore apply with equal force to the foundation for the sheet-asphalt pavement. The nature and thickness of the base will depend upon the character of the earth foundation and the care with which it is compacted, as in other types of pavement.

Base Course.—The sheet-asphalt surface is elastic and serves only as a wearing course. It cannot have stability unless adequately supported by a rigid base. Various kinds of base courses have been used, such as macadam, tar macadam, natural cement concrete, Portland-cement concrete, and old brick and block pavements. Portland-cement concrete is specified almost exclusively for new construction. Sometimes sheet asphalt is employed for resurfacing badly worn brick or block pavements, and on rare occasions is placed on top of old macadam. When properly carried out, resurfacing can be successfully accomplished in this way, but asphaltic concrete is more commonly employed in such instances.

The thickness of base depends upon the character of the soil constituting the foundation, and the class of traffic to which the pavement will be subjected. For business streets where the individual loads are heavy the base is 6 in. thick when over a good subsoil, and a greater thickness if the soil is anything other than strictly first class.

For residence street paving the base need not be so thick and for average conditions 5 in. will be adequate. On exceptionally

good soil and for light traffic the base may be as thin as 4 in., but the use of so thin a base is rarely justifiable.

The materials used for the base should be carefully selected and properly proportioned as they would be for the construction of the base for any other pavement. The mixture for the con-

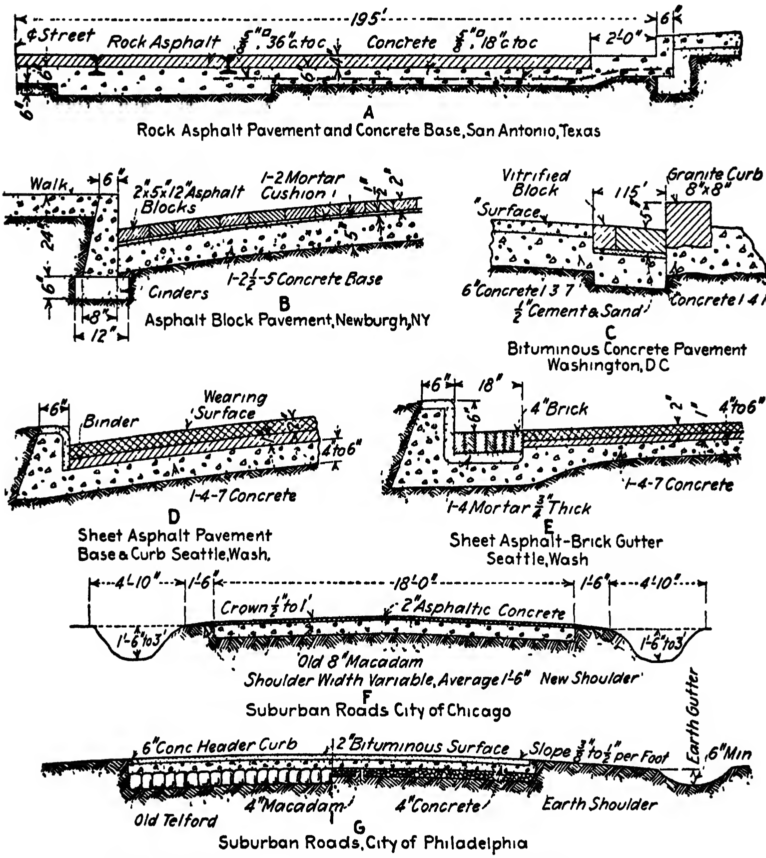


FIG. 78.—Cross-sections for sheet pavements and roads.

crete may be either 1-2½-5 or 1-3-6, depending upon the nature of the materials and the kind of subsoil.

There is some tendency to finish the base with a rough or porous surface, or to shape it carelessly, which results in considerable variation in texture. Stability and durability in the asphalt surface require that the surface of the base shall have a uniform texture, free from porous patches and also free of patches of mor-

tar. It should not receive a troweled finish. If the sheet-asphalt surface varies in thickness it will compress more during rolling in some places than in others and the difference in density will result in the pavement developing undulations under traffic. Hence the necessity for a base that is carefully constructed to the required cross-section.

Binder Course.—Formerly the sheet-asphalt wearing surface was placed directly on the base, but it was found to creep and become uneven, and the intermediate or binder course was accordingly introduced. The binder course consists of a layer of asphaltic concrete placed directly on top of the concrete base. The thickness of the binder course depends upon the class of traffic and the total thickness of wearing surface that it necessitates. For heavy-traffic streets the binder course is usually 1½ in. thick, while for residences or other light-traffic streets 1 in. is sufficient. For streets carrying traffic made up of very heavy individual loads, it is recommended that the binder be 2 in. thick.[1]

The binder mixture is of two types, known respectively as open binder and close binder, the difference being in the grading of the mineral aggregates.

Open Binder.—The open binder is composed of stone ranging in size from ¼ or ½ in. to 1 in., to which is added from 5 to 8 per cent. of asphalt cement. Other size limits for the stone are sometimes specified, but in this type of binder no attempt is made to secure a dense mixture, nor are the voids filled with the asphalt cement as is apparent from the proportions given. The asphalt cement must be sufficient in quantity to coat all the stones so that when rolled the binder will be well cemented together. The surface of the binder course after it is rolled will be porous and open; hence the designation that is given it. The surface interstices of the binder course will be filled with the surface mixture by the rolling.

Close Binder.—Close binder differs from open binder in that the mineral aggregate is graded so as to secure a fairly dense mixture in which the voids are filled. This is accomplished by mixing broken stone and sand in such proportions that the sand will fill the voids in the stone. The stone ranges in size from 1 in. down and crusher-run is frequently employed. The sand should be well graded, but the requirements are not so rigid as those for

[1] Mr. D. T. Pierce, in No. 133 of "The American City Pamphlets."

sheet-asphalt surface mixtures. The following specification is typical of those used for the close binder:[1]

"The binder stone shall be graded from 1 in. downward, to which sand shall be added so that the mixture shall contain between 25 and 35 per cent. of material passing a 10-mesh sieve."

The amount of asphalt cement required for the close binder is somewhat greater than that required for the open binder.

The close binder is recommended for streets carrying moderate or heavy traffic and the open binder is permissible only on very light-traffic residence streets.

Character of Materials for Binder Course.—The stone for the binder course must transmit the load from the wearing surface to the concrete base, but since the medium is somewhat plastic the requirements for the stone are not exceedingly rigid. Any good, hard, tough limestone, or trap rock or granite may be used. The stone should be clean and should run with reasonable uniformity as to grading. The sand for the close binder should be of the quality and cleanness required for high-class concrete.

Old Surface Mixtures for Binder.—Old sheet-asphalt surfaces that have been removed in resurfacing streets are utilized for the preparation of close binder. The old surface mixture is melted in kettles heated by steam and then mixed with the proper amount of stone. Additional asphalt cement is added to renew the life of that which is in the old surface mixture. Suitable precautions must be taken to insure that the old mixture is thoroughly broken up and distributed through the mass of stone and that the right amount of new asphalt cement is added. The asphalt cement in the ordinary binder course is of the same quality as that used for the surface mixture except that it can advantageously be about 15 points softer.

Asphalt Paint Coat for Binder.—In a few instances the binder course as described above is omitted entirely and instead a paint coat of asphalt cement is applied to the concrete base. In order to insure adhesion, the asphalt cement is heated and then removed to a safe distance from the fire and fluxed with commercial naphtha. This softens the cement sufficiently to insure adhesion to the concrete base. The naphtha quickly evaporates, leaving a layer of asphalt cement on the concrete. This method has not had sufficient tests under diverse con-

[1] City of Chicago Specifications for 1916.

ditions to warrant general adoption, but has been used very successfully by some of the cities in California.[1]

Surface Mixture.—The surface mixture for the sheet-asphalt pavement consists of sand, filler and asphalt cement.

Sand.—It has long been recognized that the stability of the sheet-asphalt surface depends to a large extent upon the care with which the mineral aggregate is graded. Experience with cement mortars has shown the importance of using a sand that is properly graded, to insure density and strength, and the sand grading is no less important in the sheet-asphalt surface mixture. Inasmuch as the mineral aggregate comprises about 90 per cent. of the volume of the surface, it is reasonable to expect that it needs to be carefully selected and properly graded. The sand should be clean and free of slate, shale or other friable material. It is generally thought that sharp sand is better than sand made up of rounded particles, but this cannot be stated as a general fact because successes and failures have been recorded with both classes of sands.

Filler.—The filler is the portion of the mineral aggregate passing the 200-mesh screen and may consist of finely ground rock dust or of Portland cement. The filler plays an important part in the mixture, since it serves to fill the small voids and to give density to the surface. A good filler should not only be fine enough to pass the 200-mesh sieve, but also contain a good percentage of particles that will pass a 400- and also a 600-mesh sieve. Since sieves are not made commercially with more than 200 meshes per inch, the amount of the finer particles is estimated by a modification of the method of elutriation which is employed in soil analysis. The method is described in Chapter V. Portland cement is a desirable filler since it is finely ground and is made up of very durable particles. It is more expensive than limestone dust, and for that reason the stone dust is often used. Limestone dust ground to the proper degree of fineness is widely used for filler, and while it is probably not as good as Portland cement, it is satisfactory. Silica dust is also employed for filler and seems to be as good as Portland cement. In the preparation of stone dust for the filler, the stone is first heated so as to thoroughly dry it and then crushed and finally ground in a ball mill using flint pebbles for the abrasive. Some grind-

[1] Mr. A. E. Loder in "California Highways," Jan. 1, 1915.

ing mills use steel rollers for grinding but the resulting product is usually not as finely ground as that produced in the ball mill.

Established Gradings.—The following gradings are recommended[1] for sheet-asphalt surface mixtures. These have been well established in practice and in general it can be said that the nearer the surface mixture approaches these in composition the more certain the pavement will be to have the desired stability. It will be noted that the various sizes are separated into three groups, and while it is desirable to have the specified amount of each size, it is not always possible to secure sands so graded. If each group is present in the right amount, that is sufficient.

TABLE 20.—STANDARD SHEET-ASPHALT GRADINGS

	Per cent by weight Heavy traffic		Light traffic	
Bitumen.	10.5		10.0	
200-mesh, filler.	13.0		10.0	
100-mesh	13.0	39.0	9.0	18.0
80-mesh	13.0		9.0	
50-mesh	24.0	34.5	26.0	38.0
40-mesh	10.5		12.0	
30-mesh	8.0		10.0	
20-mesh	5.0	16.0	8.0	24.0
10-mesh	3.0		6.0	

The finer portion of the mixture is the most important and the grading may more safely depart from the above as regards the material above the 40-mesh size than as regards the material finer than the 40-mesh. The amount of filler that can be used in a mixture depends upon the amount of fine sand present.

TABLE 21.—COMPARATIVE SUPERFICIAL AREAS OF FINE AGGREGATES

Material	Number of particles per pound	Surface area of particles per pound (square feet)
Ordinary sand	129,000,000	44,378
Sand of which 30 per cent. passes the 80- and 100-mesh, and 7 per cent. passes the 200-mesh	232,075,000	60,503
Filler or dust.	192,715,475,500	527,820

The amount of bituminous cement required is dependent upon the grading of the mineral aggregate and especially upon the

[1] "The Modern Asphalt Pavement," by Clifford Richardson.

proportion of the finer material in the mixture. The bituminous cement must coat all of the particles and the amount required will, therefore, vary with the surface area to be covered. The foregoing table shows the enormous increase in superficial area per unit weight with a decrease in the size of the particles.[1]

CONSTRUCTION OF THE PAVEMENT

The concrete base is finished and ample time is allowed for the concrete to set before the binder course is placed. If the binder is hauled too soon, injury to the base will result unless

FIG. 79.—Spreading sheet asphalt mixture.

a plank driveway is provided for the wagons hauling the binder. The base should be clean and dry when the binder is spread.

The binder course is mixed in the twin-pug type of mixer which is also used for mixing asphaltic concrete. The stone must not be too hot or some of the asphalt cement will run off while the mixture is being hauled; it must not be too cold or it cannot be spread and rolled satisfactorily. For most materials 275° to 325°F. is about the permissible range of temperature, but this is subject to some variation for the different asphalt cements.

The binder is dumped on the concrete in advance of the point of spreading and is shoveled into place and raked to a thickness that will, when rolled, give the prescribed thickness of binder course. Experienced rakers need no guide in this operation and

[1] Mr. D. T. Pierce in No. 133 of "The American City Pamphlets."

usually none is employed except possibly a line on the curb at the top of the layer. As soon as spread, the binder is rolled, first with a 3-ton tandem roller and later by one weighing 8 to 10 tons. The rolling must proceed rapidly so that compression is secured before the asphalt cement cools too much. The rolling is carried out both crosswise and longitudinally and is a vital part of the construction, especially as regards the evenness of the finished surface. Only a skilled operator can be expected to secure satisfactory results.

The wearing course must be placed soon after the binder course has been rolled. It is especially desirable that close binder be covered with the wearing course the same day it has been laid,

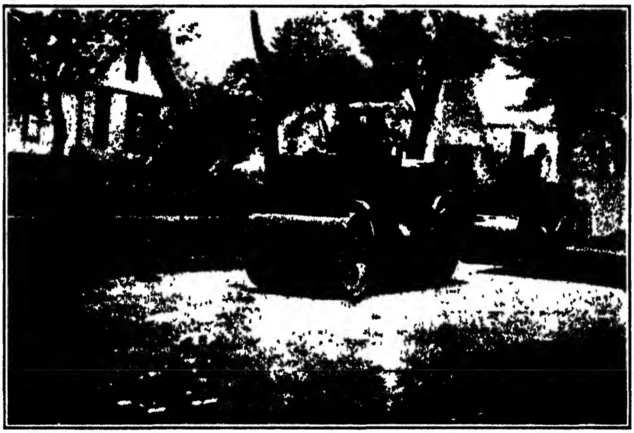


FIG. 80.—Rolling sheet asphalt surface.

and it is safer to follow the same rule for all classes of sheet-asphalt construction.

The mixture for the surface is prepared by weighing the sand, filler and asphalt cement into a twin-pug mixer and thoroughly combining the ingredients by mixing. The temperature should be somewhat higher than for the binder material. With many kinds of asphalt cements a temperature of 350°F. may be reached without injury to the materials. Other asphalts must be handled at a somewhat lower temperature.

The amount of asphalt cement required for the surface mixture depends upon the character of the asphalt cement to a small degree and upon the character and grading of the sand and the amount of filler, as has been noted. Specifications generally

give the limits for the amount of bitumen, but within these limits the amount can be varied to suit conditions. The asphalt cement must be used in sufficient quantity to coat all of the particles. The finer particles have a very much greater surface per pound than do the coarser, as is shown by Table 21. It is, therefore, apparent that the amount of asphalt cement necessary in any mixture will depend upon the grading of the mineral aggregate and especially upon the amount of fine sand and filler contained therein. The appearance of the mixture is the best guide for proportioning the asphalt cement and to an experienced plant man the characteristics of a suitable mixture are well understood. As a check on quality of the mixture, the pat test devised by Mr. Clifford Richardson has been widely used. He describes it as follows:[1]

The Pat Test.—"A small wooden paddle with a blade 3 or 4 in. wide, 5 or 6 in. long, and ½ in. thick, tapered to an edge at one end and with

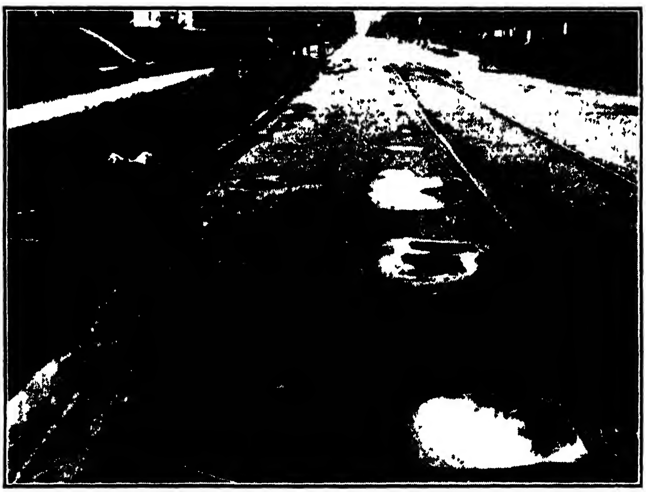


Fig. 81.—Sheet asphalt surface destroyed by concentrated traffic.

a convenient handle at the other, is used to take as much of the hot mixture from the wagon as it will hold, being careful to avoid any of the last droppings from the mixer which may not be entirely representative of the average mixture. Samples of mixture should never be taken from the mixer itself, but only from the wagon after mixing is completed.

"In the meantime a piece of brown Manila paper with a fairly

[1] "The Modern Asphalt Pavement," by Clifford Richardson.

smooth surface, 10 to 12 in. wide, and torn off at the same length from a roll of this paper, which can be had at any paper warehouse, is creased down the middle and opened out on some very firm and smooth surface of wood, not stone or metal, which would conduct heat too rapidly. The hot mixture is dropped into the paper sideways from the paddle and half of the paper doubled over on it. The mixture is then pressed down flat with a block of wood of convenient size until the surface is flat. It is then struck five or six sharp blows with the block until the pat is about ½ in. thick.

"The paper will be found to be stained to a different degree depending upon whether there is a deficiency, a proper amount or an excess present.

"In this way the amount of asphalt cement to use in making a mixture can be readily regulated, and the pat papers obtained will be evidence of the character of the mixture turned out. Where a laboratory examination is to be undertaken, a sample of surface mixture which is made from the material compressed between the paper can be used for this purpose, trimming it down into the proper form and sending it, accompanied by the paper, for the purpose."

The surface mixture is hauled to the work in covered wagons and is dumped on metal or wooden platforms or on the binder course at a distance from the point of laying that will necessitate the entire load being shoveled into place. When shoveled into place, the mixture is thoroughly broken up with the rakes and is spread to the proper thickness for rolling. The rolling begins as soon as possible after the spreading, the light tandem roller being used first and being followed by the 8- or 10-ton tandem roller. Here again the character and uniformity of the surface will depend to a considerable extent upon the skill of the roller operator. A uniformly smooth surface will result if the rolling is properly done and unevenness is inevitable otherwise. Fig. 79 shows the method of spreading the surface mixture and Fig. 80 the rolling.

The surface is sometimes dressed lightly with cement or stone dust prior to the final rolling, although the necessity of this is a mooted point.

Asphalt Plants.—The plant required for making the mixtures used in sheet-asphalt and asphaltic concrete pavements is described at the end of the chapter. The filler is not heated before being added to the mixture. The twin-pug mixer is adapted to making both the surface mixture and the binder course, but shorter and fewer paddles are used for mixing the binder.

Proportioning Asphalt Cement.—The proportion of asphalt cement is determined by weight. Since it is desired to use enough bitumen to coat all the particles, it is apparent that a more rational method would be to proportion the asphalt cement by volume. As a matter of convenience and accuracy, however, weighing is resorted to. The weight of asphalt cement per unit volume varies considerably, and if the proportioning is by weight, account must be taken of the variation in the specific gravities of the asphalt cements that might be used. Attention is also called to the fact that the percentage of bitumen is always specified not the percentage of asphaltic cement. This is necessary

Fig. 82.—Results of use of poor asphalt and improperly graded sand.

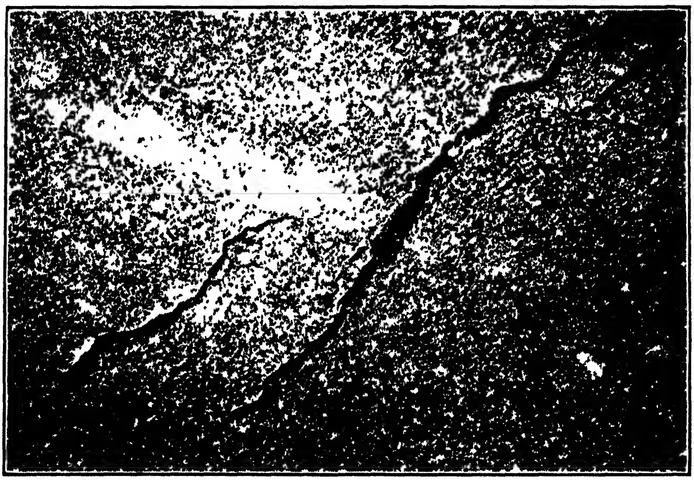
because of the differences in the proportion of bitumen in the various asphalt cements. In determining the amount of asphalt cement to use it is, therefore, necessary to take account of the specific gravity and bitumen content of the cement.

To illustrate the significance of these facts in proportioning the asphalt cement in a paving mixture, consider a sheet-asphalt surface mixture in which the percentage of bitumen by weight is 8.9. Assume that Trinadad Lake asphalt cement were used in which the percentage of bitumen is 65 and the specific gravity 1.28. The percentage by weight of the asphalt cement necessary to give 8.9 per cent. of bitumen is $8.9/0.65 = 13.5$ per cent.

If the mineral aggregate has a specific gravity of 2.65, the

actual percentage of asphalt cement by volume is equal to $2.65/1.28 \times 13.5 = 27.0$ per cent.

a



b

FIG. 83.—Showing defective sheet asphalt surfaces. In (*a*) the asphalt cement is too soft and in (*b*) it is too hard. (Views about one-half natural size.)

If, however, an asphalt cement produced from petroleum were used, the percentage of bitumen in the asphalt cement would

be about 99.5, and the specific gravity about 1.03. The percentage of the asphalt cement required by weight would be substantially the same as the percentage of bitumen. The percentage by volume in the example cited would be $2.65/1.03 \times 8.9 = 22$ per cent.

Since the bitumens extracted from the various asphalt cements vary somewhat in specific gravity, a proportion based on weight is not exactly a constant proportion by volume. This is the reason for the variation in the allowable percentage of bitumen provided for in specifications.

Some Features of Design.—If a street has sufficient longitudinal slope to insure that no water will stand along the curb, the straight concrete or stone-block curb may be used, but if the slope of the gutter is less than 0.5 per cent. it is better to design the street with the combined concrete curb and gutter, or with a straight curb and block gutter.

It is undesirable to use sheet asphalt on a street where vehicles continually stand along the curb unless that portion of the street is paved with blocks of some kind. Wood-block and grouted vitrified-brick surfaces are used for that part of the roadway.

The maximum grade for which the sheet-asphalt surface is permissible depends upon the kind of vehicles that use the surface. If the horse-drawn loads are fairly heavy, the grade probably should not exceed 4 per cent., but for automobile traffic and light-team traffic the grade may be steeper. Instances of sheet-asphalt surfaces on grades up to 8 per cent. have been noted and no especial difficulty is reported.

Where street car tracks occupy the middle portion of the street, there is a decided tendency for traffic to concentrate on the strip of pavement between the track and the curb, especially if the track paving is rough or noisy. This can be overcome to some extent by paving the car track area with sheet asphalt or wood blocks. Where traffic concentrates on the sheet asphalt, creeping and unevenness quickly develops and the pavement wears out very rapidly (see Fig. 81).

Characteristics of the Sheet-asphalt Surface.—The sheet-asphalt surface is compared with other pavements in another chapter. It is desired here to call attention to certain characteristics that are inherent. Sheet asphalt requires a certain amount of traffic to keep the asphalt "alive." It is noticeable

that on light-traffic streets the part of the pavement next the curb becomes granular and sometimes cracks badly, while the middle portion is kept in good condition by the action of traffic. Sheet asphalt also deteriorates rapidly under concentrated steel-tired traffic such as may be expected on a narrow street with a busy double-track car line.

ASPHALT-BLOCK PAVEMENTS

The asphalt-block pavement surface is constructed of blocks of a mixture similar to that used for sheet asphalt, compressed by very heavy pressure. Since the blocks are made in a specially equipped factory, all of the details of manufacture are subject to close control and the proportions of the various ingredients and the quality of the materials can be determined accurately. The product is, therefore, likely to be uniform. The blocks are formed under much greater pressure than can be secured in rolling a sheet-asphalt surface and consequently they have greater density than does the average sheet surface.

Composition of the Blocks.—Asphalt blocks are composed of graded crushed stone or sand, filler and asphalt cement. A typical specification provides as follows:[1]

> "On sifting (the mineral aggregate) not more than 3 per cent. shall be retained on a 3-mesh per inch sieve, at least 40 per cent. shall be retained on a 20-mesh per inch sieve, and at least 12 per cent. must pass a 100-mesh per inch sieve. If the stone does not contain the desired amount of fine material, mineral dust shall be added to make up the deficiency and in any case at least 5 per cent. of such mineral dust shall be added.
>
> "The mineral dust shall be any fine, absorbent, inorganic dust, not acted upon by water, the whole of which shall pass a 30-mesh sieve, and at least 85 per cent. pass a 100-mesh sieve."

The mixture for blocks contains from [illegible] to 9 per cent. of bitumen.

Size of Blocks.—The blocks are made either 3, 4 or 5 in. thick and are 12 in. long and 5 in. wide. A variation of ¼ in. from the specified size is permitted. The blocks are formed under a pressure ranging from 240,000 lb. to 360,000 lb. per block.

Subgrade.—The earth subgrade is prepared in the same manner as for the other types of pavement and has been previously described.

[1] Washington, D. C., specification, 1915.

Foundation.—The asphalt block pavement is laid on a base of either gravel, macadam or concrete, each type being constructed in the manner already described.

Bedding Course.—The bedding course is generally a layer of sand 1 or 2 in. thick, which is placed in the same manner as for the other types of block pavement.

Laying the Blocks.—The blocks are laid on the sand cushion in regular courses at right angles to the center line of the street, with the joints broken by a lap of at least 4 in. Each block is driven against the course already laid by means of a heavy maul so as to give close transverse joints, and the end joints are tightened by means of a lever from the end of the course. The surface is covered with fine sand (passing a 20-mesh sieve). A plank or an iron plate is then placed over several courses and the blocks are rammed to place by tamping through the medium of the plank or metal plate.

Characteristics.—The asphalt-block pavement has much the same appearance as the sheet-asphalt pavement, but is less slippery and somewhat more durable. Its cost is on the average about 50 cts. a square yard greater than that of sheet asphalt in the same locality, the average price being about $2.50 per square yard.

II. ASPHALTIC-CONCRETE PAVEMENTS

Asphaltic concrete is the name given to a paving mixture consisting of graded stone, sand and rock dust or other fine material, which is cemented together by a bituminous material. It receives its name from its analogy to Portland-cement concrete, although the cementing action of the bituminous material differs from that of Portland cement in that the cementing action of bitumen is a purely mechanical effect due to the stickiness of the binder.

Bituminous concrete, like sheet asphalt, is used for the wearing surface of pavements, the thickness being 2 to 3 in.

The mineral aggregate is made up of three parts: stone, sand and dust or filler.

Stone.—The stone must be tough enough to resist the crushing effect of the loads that will use the pavement. While the individual pieces of stone are at first surrounded and protected by the finer part of the mixture, eventually many of them will be exposed at the surface of the pavement. If the stone is soft or of variable

hardness, these exposed stones will crush and the fragments will be removed by traffic, leaving a pitted surface. No stone softer than good granite, quartzite or trap should be used.

If the stone is of such a nature that it absorbs any appreciable percentage of water, disintegration will occur during periods of freezing and thawing, which is of importance with pavements constructed in northern climates. At first the stones will be well protected by the seal coat but eventually this will wear down and expose the stones to traffic.

Sand.—The sand is subjected to the same crushing and abrasive action as the stone. Clean quartz sand is best but in any case the sand particles must be of some hard and durable material. Particles of clay, shale, coal or other friable material are objectionable if present in any appreciable quantity. A sand suitable for the sheet asphalt surface is suitable for asphaltic concrete.

The dust or filler may be a finely ground rock powder or Portland cement and is identical with the filler employed in the sheet-asphalt surface.

The stability of the asphaltic-concrete surface depends primarily upon the grading of the mineral aggregates, and experience has shown conclusively the limits of the various sizes for satisfactory results.

The Sand Grading.—The grading for sheet-asphalt surfaces has already been discussed at some length and the same sand grading should be employed for asphaltic concrete. If stone containing fine particles is used, these fine particles will take the place of an equal amount of sand of the same size.

Types of Asphaltic Concrete.—Two distinct classes of bituminous concrete are constructed and these are differentiated by the grading. They are known respectively as the Bitulithic and Topeka types of asphaltic concrete.

Bitulithic.—The Bitulithic type is a patented surface mixture controlled by the Warren Bros. Co., and the two essential features of the patent are: (1) the grading of sand and stone is such as to reduce the voids in the mineral aggregate below 21 per cent.; (2) the amount of stone passing the ½-in. screen and retained on the ¼-in. screen is greater than 10 per cent., and stone up to a size equal to half the thickness of the pavement is generally recommended.

A feature of importance is that the stone may exceed ½ in.

in size and usually it is as large as 1 in., or half the thickness of the wearing course. The exact grading of the stone and sand for the Bitulithic surface is determined for each piece of work after an examination of the available materials has been made. Theoretically the stone, sand and dust are proportioned in such a way as to reduce the voids in the resulting mixture to about 10 per cent., and to give what is considered a satisfactory grading for good stability. The per cent. of the various sizes of stone and sand grains will vary with the character of the material and depends upon the shape of the pieces of stone and grains of sand. Table 22 gives the sieve analysis of the mineral aggregates from two Bitulithic pavements and indicates in a general way the proportions of the various sizes required to produce a low percentage of voids. The table includes a typical specification for Bitulithic grading.

TABLE 22.—SIEVE ANALYSIS OF MINERAL AGGREGATE FROM BITULITHIC PAVEMENT

	Typical specification, per cent.	Gradings employed	
		Sample No 1, per cent.	Sample No 2, per cent.
Bitumen......	7–9½	7 6	7 02
Passing 200-mesh sieve.	4–7	5 3	4 90
Passing 100-mesh sieve.		5 0	4 27
Passing 80-mesh sieve.		3 5	2 96
Passing 50-mesh sieve.		7 9	8 44
Passing 40-mesh sieve.		3.4	1 36
Passing 30-mesh sieve..		2 6	2 56
Passing 20-mesh sieve..		2 4	2 28
Passing 10-mesh sieve.	24–32	5 5	4 04
Passing ¼-in. screen..	8–12	9 8	5 19
Passing ½-in. screen.	12–20	20 9	13 72
Passing 1-in. screen.	26–35	.	
Retained on ½-in. screen and passing 1½-in. screen.	36–50	33 7	50.28

Topeka Asphaltic Concrete.—The Topeka asphaltic concrete is a type that has some of the characteristics of the Bitulithic, but the mineral aggregate is mostly sand and ½-in. stone and contains in excess of 21 per cent. of voids and is graded so that it does not infringe the Bitulithic patent. The following is the formula for the Topeka type of asphaltic concrete established in the decree in the Topeka case:

TABLE 23.—SHOWING TOPEKA GRADING

Bitumen	7 to 11 per cent.
Mineral aggregate passing 200-mesh	5 to 11 per cent.
Mineral aggregate passing 40-mesh	18 to 30 per cent.
Mineral aggregate passing 10-mesh	25 to 55 per cent.
Mineral aggregate passing 4-mesh	8 to 22 per cent.
Mineral aggregate passing 2-mesh	Not over 10.

(Sieves to be used in the order named.)

It will be noted that a wide variation in the grading is possible under the above specification, especially in the finer portions of the mixture and it has, therefore, been found advisable to provide a closer grading for the sand in this class of pavement. In effect the Topeka type of surface is sheet asphalt plus a limited amount of stone not greater than ½ in. in size. The following are analyses of Topeka asphaltic-concrete mixtures and illustrate the care that ordinarily is taken in grading the sand.

TABLE 24.—SHOWING GRADING OF MINERAL AGGREGATES FOR ASPHALTIC-CONCRETE PAVEMENTS

	No I	No II	. III	No IV*
Bitumen	8 9	8 9	8 1	8 4
Passing 200-mesh	11 9	12 3	8 9	3 4*
Passing 80-mesh	14.5	10 8	10 7	2 5*
Passing 40-mesh	18.6	24.2	25 3	26 0
Passing 10-mesh	18.9	16 3	15 7	22 0
Passing 4-mesh	19.1	21 5	13 0	20 0
Passing 2-mesh	8 1	5 4	18 3	17.7

* Unsatisfactory grading, deficient where marked

Other Types of Asphaltic Concrete.—Many proprietary pavements of this type have been promoted but all are based on one or the other of the two types already mentioned.

Warrenite.—Warrenite is similar to Bitulithic but it is not as carefully graded and is intended more especially for rural highways. It is covered by the Bitulithic patents.

Mineral rubber, *Sarcolithic*, *Amiesite*, and *Filbertine* are proprietary pavements mostly intended to promote the use of certain kinds of materials. They involve no new basic principles and a discussion of them is of no importance herein.

Foundation for the Asphaltic-concrete Surface.—The asphaltic-concrete pavements are laid on a Portland-cement

concrete foundation and on macadam or gravel foundations. If the Portland-cement concrete is adopted it is of the same composition and thickness as for the sheet-asphalt pavement. It is thought that the Topeka type of asphaltic concrete is liable to creep on a concrete foundation if the concrete is given a smooth finish. It is, therefore, customary to finish the surface of the foundation by tamping and to avoid striking or troweling in any manner. Some engineers require that the surface be finished with a knobbed tamper so as to leave pits in the surface. These are satisfactory except that they are difficult to clean when the base is swept preparatory to laying the wearing surface.

Sometimes the surface of the base is roughened by scattering coarse (1½ or 2 in.) stones over the green concrete and tamping

FIG. 86.—Laying bitulithic pavement.

them until half bedded in the base. This produces a good bond but decreases the effective thickness of the wearing course.

In other instances the base is roughened by sweeping the mortar from around the stone just before the cement takes final set. If this work is carefully done, the corners of the stone will be exposed and will form a good anchorage for the wearing surface. Everything considered, this is probably the most satisfactory method of roughening the base.

At best there is a possibility of the wearing surface creeping and becoming uneven, particularly if the asphaltic concrete itself is not of the proper composition. This difficulty is encountered less frequently with the Bitulithic type of surface than with the other types, and less frequently with a macadam base than with

the concrete base. It is probably safe to say, however, that on any city street except one in a residence district with light traffic, the asphaltic concrete should be placed on a concrete foundation.

Macadam Base.—If the macadam base is used, an old and worn macadam may be utilized by resurfacing it to restore its shape and thickness, which should never be less than 6 in. and must be in most instances 8 in. The same thing is true of an old gravel surface that is to be used for the foundation, but unless it is of ample thickness and thoroughly compacted the surface will get out of shape due to the failure of the foundation.

The foundation may be a newly constructed macadam or gravel of good quality, but the greatest care is necessary in this case to insure an unyielding foundation. It is well known that new macadam gradually increases in density for some time after it is opened for traffic and if the asphaltic concrete is placed before traffic uses the macadam, some unevenness is almost sure to develop.

Thickness of Surface.—The thickness of the surface after rolling is rarely less than 2 in. even on light-traffic streets or roads and that thickness is used almost universally on all classes of streets and roads. It seems to be impractical to use a less thickness without its being displaced by traffic and a greater thickness is apparently unnecessary except for very heavy-traffic streets.

A few pavements have been constructed where the thickness of the surface has been made 3 in., but these are on very heavy-traffic streets.

The surface layer is ordinarily placed directly on the foundation without any intermediate or binder course such as is used in the sheet-asphalt pavement. Undoubtedly the Topeka type of asphaltic concrete would be more stable if placed on a binder course.

Mixing and Placing.—The mixing is accomplished in a plant identical with that used for sheet asphalt. The mineral aggregate and the bitumen are heated separately and combined by weighing accurately the proportion of each size of stone, sand, filler and bitumen, and then mixing in the twin-pug or some similar mixer For the Topeka type of asphaltic concrete the mineral aggregate is separated into two sizes in the storage bins, while for the Bitulithic seven sizes are recommended. The proper quantity of each size is weighed into the mixer, the dust and asphalt cement added and the whole thoroughly mixed.

The mixing is accomplished at temperatures ranging from 250°F. to 350°F., the variation being necessary on account of difference in the asphalt cement.

Laying the Surface.—The paving mixture is hauled in covered dump wagons from the plant to the place where it is to be laid and at the place of delivery the mixture is dumped on the foundation somewhat ahead of where it is to be spread. It is then shoveled to place and spread by means of rakes, care being taken to loosen the entire mass in so doing. It is then rolled with a light roller both longitudinally and crosswise of the street. On narrow pavements or country roads the transverse rolling is

Fig. 84.—Heater for tampers and smoothing irons.

impractical and all rolling is done longitudinally and diagonally. After the light rolling a heavy roller is substituted and the rolling continued in a longitudinal direction until ultimate compression is reached. Careful and thorough rolling is a very essential part of the construction because it effects not only the durability but the evenness of the pavement. The tandem type of roller is commonly used for the Topeka type of asphaltic concrete, the lighter one having a weight of about 3 tons, while the heavier should have a weight of at least 8 tons. The macadam type of roller weighing about 10 tons is recommended for the Bitulithic type of asphaltic concrete.

Dressing the Surface.—Several methods of finishing the surface are employed.

After the first rolling a light dressing of Portland cement may be spread on the surface, and subsequent rolling will incorporate the cement with the surface.

A *seal coat* of the asphalt cement may be spread with the squeegee or with brooms and this covered with pea gravel and rolled just enough to set the gravel into the seal coat. The surface is sometimes covered with pea gravel or stone chips and

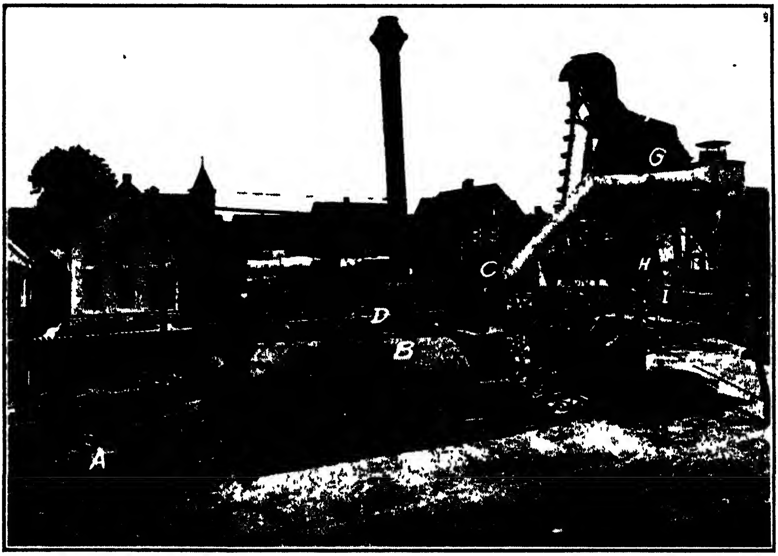


FIG. 85.—Showing essential parts of an asphalt plant. *A*. Cold sand elevator. *B*. Sand heater. *C*. Fan. *D*. Power plant. *E*. Melting tank. *F*. Screen. *G*. Hot sand storage. *H*. Weighing hopper. *I*. Twin pug mixer.

the seal coat omitted. Probably the seal coat with stone chips, or pea gravel, forms the best surface.

Suburban Roads.—Asphaltic concrete is widely used for suburban and state roads, being in most instances placed on a foundation of macadam or gravel. These roads are comparatively narrow, being seldom over 20 ft. wide and often being of less width. Vehicles are sure to cross and recross the edge of the wearing surface and if no marginal curb is employed the edge of the wearing surface will gradually break down and

start the disintegration of the surface. The marginal curb of concrete or a substantial shoulder of macadam is necessary for such roads but otherwise they are constructed in the same manner as city streets of like material. Instead of Bitulithic, the Warrenite is more commonly specified for suburban roads.

Characteristics.—The asphaltic concrete is resilient, dustless, quiet and easily cleaned. It is only slightly slippery, being less so than the sheet asphalt. Its durability depends upon many factors, but in general is about the same as sheet asphalt.

The cost varies between $1.75 and $2.50 per square yard, exclusive of grading.

Maintenance.—Assuming that the pavement has been well built, the first need will be a renewal of the seal coat and dressing. If a heavy asphaltic oil is used for this purpose it will renew the surface and restore the elasticity of the asphalt cement near the surface and thus give the pavement a new lease of life.

Patching will finally become necessary because of the formation of pot-holes.

TOOLS AND APPLIANCES USED FOR SHEET-ASPHALT AND ASPHALTIC-CONCRETE CONSTRUCTION

Mixing Plants.—Mixing plants are of many types and designs and vary in size from those that can be loaded on a single flat car and have a capacity of 1,000 sq. yd. a day to those that are permanently located in the larger cities and have a capacity up to 10,000 sq. yd. a day. Regardless of the size of plant, the essential parts are the same, the difference being only in details and size.

Sand and Stone Heaters.—The same heaters are used both for sand and stone and they consist of metal cylinders mounted so they will revolve over the furnaces. The cylinders are mounted at a slight inclination and structural angles are riveted to the inside of the shell with one leg projecting. As the cylinder revolves the material is carried up on these projecting angles until it finally drops. But since the cylinder is inclined the material will fall ahead of where it started and thus gradually move through the cylinder while being heated. A fan is provided to force heated air through the cylinder, and to remove any dust that may be in the sand.

Screens.—The material is introduced into the heater in about the proportions experience and tests show is desired but after being heated the material is elevated to a revolving screen where it is separated into two or more sizes and deposited in the storage bins. The number of bins and the sizes into which the material is separated depends upon the character of the pavement and the degree of refinement desired in the mixture. For sheet-asphalt wearing surfaces two sizes are commonly used as follows: (*a*) passing a 10-mesh screen and (*b*) retained on a 10-mesh screen and passing an 8-mesh screen. For asphaltic concrete of the Topeka type two sizes are commonly used, namely, stone passing a ½-in. screen and retained on a 10-mesh screen, and sand passing the 10-mesh screen.

For asphaltic concrete of the Bitulithic type a larger number of sizes is desirable for satisfactory grading and the following are recommended: The minimum screen opening to be 1/10 in. and the maximum not greater than 1½ in. The difference in the width of openings of the portion of the screen having openings less than ½ in. in size shall not exceed ¼ in., and in the sections having openings larger than ½ in. the difference in size between successive sections shall not exceed ½ in. The following sizes of opening prove satisfactory: 1/10-in., ¼-in., ½-in., ¾-in., 1-in., 1½-in.

Storage Bins.[1]—The hot sand and stone will retain heat for some hours and to prevent delays and to facilitate the work storage bins are provided for the hot aggregates. These storage bins are below the screen, the several compartments of the bins corresponding to the several sizes of the screen. The problem that presents itself in connection with the storage of aggregates is how to prevent segregation of sizes either when the material is deposited in the bins or when it is drawn off from them. If the materials fall directly into the bin from the screens, the fine material will fall on one side and the coarse on the other. A hopper should be provided into which they will fall and flow to a central spout and thence to the bin. The bin should be conical, at least have a conical bottom, and should be kept fairly well filled up during the working period so that the weight will keep the entire mass down to the gate. If the bin gets low the sand is likely to draw down in the middle of the bin, and the coarse

[1] See also "The Modern Asphalt Pavement" by Clifford Richardson.

particles will inevitably run down into the hollow thus formed and be drawn out first. Most troubles of this sort are avoided if the bin is worked at least half full.

Asphalt Cement Melting Tank.—The melting tanks are heated by wood, coal, or with steam coils. The tank is rectangular-shaped with a cylindrical bottom, the capacity varying from 2 to 50 tons. Regardless of the method of heating used perforated steam or air pipes are placed in the tank so that a jet of steam or air may be blown through the asphalt cement to stir it. In the larger plants steam heating and agitation are used, but in many of the smaller plants the coal or wood furnace is used for heating and air for stirring.

Mixers.—For sheet asphalt and asphaltic concrete the twin-pug type of mixer is used, the only difference between the machines for the two kinds of mixture being that the one used for asphaltic concrete has fewer and shorter paddles than are used for the surface mixture. The mixer is often steam-jacketed so that it can be kept hot during the mixing. It is placed on a platform which is high enough to allow the wagons to drive underneath. The batch is dropped into the wagon through a door in the bottom of the mixer.

Proportioning.—The basis of the proportioning is the "box" or 9 cu. ft. which is the amount commonly mixed at one batch. The mixture is set for the proper weight of each kind of material for this quantity, and all proportions are determined by actual weighing. The *Bitulithic* plants are equipped with a multi-beam scale for convenience in weighing the several portions that make up the mixture.

Rakes.—A special type of stout rake with straight tynes is used for spreading the mixtures on the street.

Smoothing Irons, Tampers.—These are of special design with metal handles so that they can be used hot.

Rollers.—The 2- to 4-ton tandem roller is used for the initial compression and the 8- or 10-ton tandem roller for the final rolling, except that the three-wheeled or macadam type is generally recommended for the Bitulithic pavement.

Asphalt Wagons.—The wagons used for hauling the surface mixture may be the ordinary 2-yd. dump bottom wagon or any similar wagon that is quick dumping and has a tight closing bottom. The motor truck with or without trailer is also widely used for the purpose.

EXAMPLES OF GOOD PRACTICE

CHICAGO[1]

Sheet-asphalt Pavement

Sand.—The sand shall be hard-grained and moderately sharp. It shall be free from loam or any other foreign material, and shall be so graded as to produce, in the finished surface mixture, the mesh requirements elsewhere herein specified. It shall contain not to exceed six (6) per cent. of sand that will pass a 200-mesh sieve.

Binder Stone.—The stone or gravel to be used for asphaltic concrete binder shall be hard and durable, free from all foreign substances, and of varying sizes from one (1) inch downward.

Asphaltic-concrete Binder.—The asphaltic-concrete binder shall be prepared as follows:

The binder stone and sand shall be heated to from two hundred (200) degrees to three hundred and twenty-five (325) degrees F., measured off separately at the mixer and then mixed with asphaltic cement, in such proportions that the resulting aggregate will contain, by weight, material passing a 10-mesh screen between twenty-five (25) and thirty-five (35) per cent. and bitumen in quantity from five (5) to eight (8) per cent. of the entire mixture. The proportion of asphaltic cement shall at all times be determined by actual weighing with scales attached to the asphaltic-cement bucket. The concrete thus prepared shall be a compact mass containing a minimum of voids. With the permission of the Board of Local Improvements in lieu of the above, where available, old asphaltic surface paving mixtures may be used in combination with the binder stone, such mixtures having been previously crushed or disintegrated and augmented with fresh asphaltic cement, so that when combined the resulting concrete shall form an equally compact mass and correspond as to aggregate passing a 10-mesh screen, and its contained percentages of bitumen with the requirements for the mixture previously specified.

NOTE.—Inasmuch as the percentage of bitumen in the asphaltic-concrete binder will depend upon the grading of the aggregate, the proportions of the materials used in the above may be varied by the Board of Local Improvements, but only within the limits designated.

[1] From Specifications in use in 1916.

The asphaltic-concrete binder shall be brought to the work in wagons, covered with canvas or other suitable material, and upon leaving the plant shall have a temperature of two hundred (200) degrees to three hundred and twenty-five (325) degrees F. It shall then be placed upon the street and raked to a uniform surface to such depth that, after being rolled and thoroughly compacted, it shall have a thickness of one and one-half (1½) inches. The surface after compression shall show at no place an excess of asphaltic cement, and any spots covering an area of one (1) square foot or more showing an excess of asphaltic cement shall be cut out and replaced with other material. Smaller spots may be dried by the use of stone dust and smoothers. Any asphaltic-concrete binder broken up during the process of laying must be removed and replaced with new material.

Wearing Surface.—The surface mixture shall consist of asphaltic cement....... .....(the desired filler) and sand, so proportioned that the mixture will contain average proportions by weight of the whole mixture as follows:

Bitumen.	11 0 to 13 5 per cent.
(Filler) passing a 200-mesh sieve.	10 0 to 15 0 per cent.
Sand passing an 80-mesh sieve.	18 0 to 36 0 per cent.
Sand passing a 40-mesh sieve.	20 0 to 50 0 per cent.
Sand passing a 10-mesh sieve	8 0 to 25 0 per cent.
Sand passing a 4-mesh sieve.	0 to 10 0 per cent.

Sieves to be used in the order named.

The item designated as "........ (filler) passing a 200-mesh sieve" within the limits named herein includes in addition to the .... (filler) fine sand passing a 200-mesh sieve not exceeding four and one-half (4½) per cent. of the total mixture, and such 200-mesh mineral dust naturally self-contained in the refined asphalt.

The item designated as "Sand passing an 80-mesh sieve" within the limit named herein includes, in addition to sand passing an 80-mesh material contained in the .. .. (filler) and such 80-mesh material naturally self-contained in the refined asphalt.

The sand and the asphaltic cement shall be heated separately to about three hundred (300) degrees F. The maximum temperature of the sand at the mixer shall not be in excess of three hundred and seventy-five (375) degrees F. and the maximum

temperature of the asphaltic cement shall not exceed three hundred and thirty-five (335) degrees F. at the discharge pipe. The .... (filler) shall be mixed with the hot sand in the required proportions, and then these shall be mixed for at least 1 min. with the asphaltic cement at the required temperature and in the proper proportions in a suitable apparatus so as to effect a thoroughly homogeneous mixture.

The proportion of asphaltic cement shall at all times be determined by actual weighing with scales attached to the asphaltic cement bucket.

The .... (filler) and sand must also be weighed unless a method of gaging approved by the Board of Local Improvements is used.

If the Board of Local Improvements directs, the proportions of the materials in the surface mixture shall be changed within the above limits for any part or parts of this improvement.

The contractor shall furnish every facility for the verification of all scales or measures.

The surface mixture shall be hauled to the work in wagons provided with a canvas or other suitable cover. It shall leave the plant at a temperature between two hundred and fifty (250) and three hundred and thirty-five (335) degrees F., as suitable for the asphalt used. Upon arrival at the street it shall be dumped at such distance from the work that all of the mixture must be turned and distributed to the place where it is to be raked. It shall be spread while hot upon the asphaltic-concrete binder, which must be dry and free from foreign matter. The last load of the day shall be spread at least 1 hr. prior to the official time of sunset. The lowest permissible temperature of the surface mixture when spread, shall vary from two hundred and thirty (230) to two hundred and eighty (280) degrees F., according to the asphaltic cement used. After receiving its ultimate compression by rolling, it shall have a thickness of two (2) inches. The initial compression must be effected by means of a small roller, after which a small amount of hydraulic cement shall be swept over the surface. Final compression shall be effected by a roller of not less than two hundred (200) pounds per inch tread. The rate per hour of rolling with the heavier roller shall not exceed two hundred (200) square yards of surface.

ASPHALTIC CONCRETE FOR SURFACING[1]

Asphaltic concrete used for topping old macadam streets and roads in the outskirts of Chicago is made under city supervision in a railroad portable plant. It is of the Warren type, cost $15,000 and can turn out material to pave 2,500 sq. yd. of 2-in. top in a 9-hr. day. Topping old macadam roads can be done at 60 cts. per square yard. The estimated life, without repairs, is 5 years, and with reasonable repairs 20 years. Country roads have cost about 20 cts. per yard per year to maintain, and the condition is not satisfactory at that.

Costs per square yard are: 89,123 sq. yd. of sheet asphalt, 95 cts.; 30,440 sq. yd. on brick $1.06; 30,900 sq. yd. on granite, 55 cts., and 376,960 sq. yd. on macadam, 20 cts.

Methods of preparing old macadam roads for a 2-in. asphalt topping in Chicago differ somewhat in different localities. Where the existing surface is in good condition and has suitable line, grade and contour, the surface is swept thoroughly to remove all the loose particles and expose the rough stone. If any depressions exist they are filled with binder and tamped. In this way the existing road is made parallel to and 2 in. below the finished surface. Along the edges of the road care is taken to provide a good shoulder to hold the pavement in place. Where the soil is soft, stone is added and the shoulder thoroughly rolled.

Where the old macadam is flat or depressed at the center the sides are picked up and the material moved to the center. Care is taken not to lower the sides so that less than 4 in. of stone exist in a firm condition. If additional material is required the street is scarified to a depth of 3 in. and material added, making the center at least 10 in. in depth and the sides 6 in. About 2½ in. is found sufficient for drainage from the crown to the edge.

PERCENTAGE OF MIX

The percentage of mix for the topping will average 6.5 bitumen; 37.2 torpedo sand; 52.3 stone; and 4 filler. The aggregate is Portland cement, torpedo sand and crushed granite, ranging from ¼ to 1 in. in diameter and costing $2.25 per cubic yard. A mile of road is surfaced each week at a cost of 70 cts. per square

[1] Walter L. Leiniger, Superintendent of Streets, City of Chicago, in *Engineering Record*, Aug. 15, and Oct. 3, 1914.

yard. At the plant the force consists of a foreman, chief drum man, kettle man, mixer man, 2 timekeepers and material men, 25 laborers, 18 teams, 1 assistant chemist and 2 watchmen. The field force comprises 1 asphalt foreman, 2 rakers, 2 smoothers, 2 tampers, 15 helpers, 2 watchmen and 2 roller engineers. These men produce and lay 2,500 sq. yd. of 2-in. top per day.

BITUMINOUS CONCRETE PAVEMENT CONSTRUCTION IN WASHINGTON, D. C.[1]

In composition this pavement is practically a sheet-asphalt pavement, the binder and top courses of which have been consolidated into a single course by combining a sheet-asphalt surface mixture with a binder course composed of run-of-crusher stone, in such proportions that the surface mixture fills the voids in the stone.

The proportions of coarse and fine aggregate for this concrete were fixed after a number of sieve tests of local sand and trap rock at about 2 parts by volume of stone to 1 of sand, to which is added about 5 per cent. of dust to supply the deficiency in fine material of the stone aggregate.

The specifications for bituminous concrete surfacing provide for laying both on a concrete base, similar to that used for sheet asphalt, and on a broken-stone or gravel base. The ingredients consist of crushed trap rock devoid of dust and varying in size from 1 in. to screenings, sand, mineral dust and asphaltic cement. A hard-grained moderately sharp sand is used. Upon sifting at least 25 per cent. must be caught on a 20-mesh sieve and 5 per cent. pass an 80-mesh sieve. A deficiency in fine sand may be corrected with mineral dust, which consists of any fine Portland cement or limestone dust at least 86 per cent. of which passes a 100-mesh screen and the whole of which passes a 30-mesh. A refined fluxed asphalt is used, free from water and having a penetration of from 40 to 70 when tested in a Dow machine at 77°F. with No. 2 needle, 100 grams for 5 sec. The penetration and percentage of cement used is varied to fit conditions of traffic and variation in material but in no case is more than 7 to 9 per cent. of bitumen soluble in carbon disulphide used.

The paving mixture is prepared in an asphalt paving plant. The sand and stone after being heated in separate dryers to about

[1] Capt. Mark Brooke in *Engineering and Contracting*, Apr. 7, 1915.

300°F. are conveyed to the box used for mixing binder stone where the hot asphaltic cement and cold limestone dust are added and the whole thoroughly mixed. The method of laying is described in the specifications as follows:

The mixture will be hauled while hot to the site of the work and shall be covered until deposited on the street. The temperature at the time of dumping shall not be less than 220°. The hot mixture shall be evenly spread with hot tools upon the base to such a thickness as will make a layer 2 in. thick after rolling. It shall then be rolled with a steam roller weighing not less than 1 ton per foot of tread of roller, until no further compression occurs. After the rolling of the asphaltic-concrete wearing surface has been completed there shall be spread over such surface a thin coating of asphaltic cement as used in surfacing not to exceed on an average ¼ gal. to the square yard, of such consistency as shall be approved, which shall be thoroughly brushed into the wearing surface so as to fill all voids and smooth out any minor unevenness of the said surface. There shall then be spread over and rolled into this flush coat a thin layer of trap screenings so far as practical, devoid of dust, in size from 38 in. down, to secure a gritty, non-slippery surface.

This material, particularly if there is a slight excess of cement, tends to separate during the haul to the street, the fine material and cement working to the bottom of the wagon.

In cold weather it is essential that the material arrive on the street amply hot, as the slightest chill stiffens it and makes it very difficult to spread and roll. For these reasons, aside from other considerations, motor trucks have been found to be better than carts or wagons for the hot haul.

Some difficulty has been experienced in applying the flush coat in sufficient quantity to seal the surface without causing the formation of a mat which would cover up the stone aggregate and produce a slippery surface.

The specification originally provided for the application of a thin coat of hot asphaltic cement. On several streets the hot cement used in the paving mixture was tried. It was poured from pots, broomed and squeegeed and a small hand spreader was used, but notwithstanding the care taken to get it on thin it was found impossible to prevent the formation of a mat which became very slippery in spite of the application of the stone chips. On one street this surface was so objectionable that it has

been necessary to sand it each summer. The effect of the coarse sand and the partial wearing off of the mat and consequent exposure of the stone are gradually curing this slipperiness.

After this experience the hot application was abandoned for an asphaltic emulsion which is applied cold, broomed in and then covered with chips. After the evaporation of the water and emulsifiant (ammonia) a light coating of asphalt is left. This method gives the rough mosaic surface which is desired but it is questionable if there is sufficient body of cement to bind the fine material and effectually seal the surface.

It is believed it would be practicable to get a satisfactory flush coat by applying a lighter cement with a power distributor such as is used in macadam surface and penetration work and the engineer department intends to try this method.

An apparent defect in this specification is the lack of any requirement as to grading of the stone. It is evident that the composition of the mixture might vary within wide limits. However, from Table 25 showing the average of the tests of the mixtures actually laid in five working seasons, it will be seen that the aggregate runs fairly uniformly.

TABLE 25.—AVERAGE GRADING, BITUMINOUS CONCRETE MIXTURES WASHINGTON, D. C., 1910–14

Retained on square mesh	1910	1911	1912	1913	1914
1-in. mesh.	1 0	0 0	0 3	0 0	0 0
¾-in. mesh.	13 0	20.2	12 8	5 0	0 0
2-mesh.	30 0	18 0	18.7	13 7	17 6
4-mesh	19 2	21 2	26 3	19 2	25 2
8-mesh	2 6	9.6	9.5	17 0	14 5
10-mesh.	0 3	1.0	1.3	3 8	2 8
20-mesh.	1 3	3.0	4 9	10 2	8 0
40-mesh.	10 7	6 6	8 0	13.0	12 3
60-mesh.	10 7	7 0	7 0	6.1	5.8
80-mesh.	6 2	3 6	3 5	3 2	3 2
100-mesh.	1 6	1 7	1 2	1.0	0 8
Passing 100-mesh	3 2	7 8	6 3	8.0	8 8
Spec. gr. stone.	2 85	. .	2 93	2.97	2 86
Spec. gr. sand.	2 69		2 70	2 70	2 63
Per cent. of voids in aggregate.	26 4	.	21 98	20 76	21 39
Per cent. bit. sol. in CS_2 (not including flush coat).	7 1	6.8	6 9	7 35	6 80
Average penetration of asphaltic cement	60.0	60 0	60 0	60 0	60.0

The sand is tested before use for compliance with the specification for that material, but no attempt is made at selection, or separation or grading of any sort of the run-of-crusher stone. The material below the 8-mesh is fairly uniform due no doubt to the sand entering into this part of the mixture. The increase in material passing 100-mesh from 1910 to 1911 is due to a change in specifications increasing the amount of mineral dust. In the 1910 mixture only about 1 per cent. of dust was added, whereas not less than 5 per cent. has been used since.

The stone used up to this year was a trap from a quarry near the Potomac about 30 miles above Washington. The 1914 stone is a differnet stone from a quarry on the Susquehanna near Havre de Grace, Maryland.

The average price of this pavement laid to a thickness of 2 in. after compression, including a 6-in. gravel concrete base and grading for same, has been $1.79, which includes a 5-year guarantee. The average cost of macadam base has been $0.345 making cost of bituminous concrete pavement on macadam base $1.31.

The average price of standard sheet asphalt with base during the same period was $1.84 and exclusive of base $1.06, with same guarantee.

Bituminous concrete surfacing has been laid on both concrete and macadam base, the latter usually consisting of an old macadam roadway shaped to a proper cross-section. The use of a well-bonded macadam roadway as a base has not in practice effected as great a saving as might have been expected as the work of scarifying, building up on the quarters and rolling necessary to bring the macadam to a cross-section 2 in. below and exactly parallel to the finished surface has always proved much greater than was anticipated. Moreover, this shaping of the old roadway very largely destroys its bond, one of the valuable assets of the old pavement. For these reasons the use of macadam base has been discontinued save in exceptional cases.

It is too soon to determine the ultimate economy of this pavement or its relative value as compared with sheet asphalt with which it is in competition in Washington. Its first cost is slightly less than that of sheet asphalt; it apparently requires less traffic to keep it in good condition, and will carry heavier traffic than sheet asphalt. It has been notably free from the defect

of creeping or rolling which has become more significant since the advent of fast-moving motor traffic, and it has an ideal surface for horse traffic.

On the other hand it is not so dense as a sheet-asphalt top mixture and may not prove as durable.

As far as can be judged from the limited experience of our five seasons' work, this pavement will prove satisfactory and its use will be continued on an increasing scale.

COST OF ASPHALT REPAIRS IN DAYTON[1]

During a test of a new portable asphalt repair plant at Dayton, Ohio, from Dec. 1 to 8, inclusive, the costs ranged from 36 to 51 cts. per square yard. Old materials were used in a Smith mixer. The following table of costs was obtained by Mr. C. O. Dustin, staff engineer, of the Bureau of Municipal Research, Dr. L. D. Upson, Director:

TABLE 26.—OPERATION STATISTICS AND UNIT COSTS WITH OLD ASPHALT

Date	Hours plant run	Number batches mixed	Minutes required per batch	Cubic feet mixed	Square yard laid	Total cost	Cost per square yard
1	5	14	21 0	210	84 0	$32 60	$0 39
2	9	32	17 0	480	194 0	70 35	0 36
3	9	39	14 0	624	197 5	84 10	0 43
4	9	40	13 5	640	203 0	88 10	0 43
5	6	29	14 0	464	115 5	57 30	0 51
6	9	34	15 0	544	173 0	69 40	0 40
8	9	21	22 0	384	123 0	59 35	0 48
Total.	56	212		3,346	1,086 0	461 20	
Average.			16 0	557	181		0 42

These costs, calculated to a 2-in. equivalent, would be about one-half of the above figures, as most patches were 4 in. thick.

Mr. Dustin reports that it was impossible to obtain a definite proportion of aggregate and bitumen when remelting old material, but analysis of early runs indicated 17 per cent. bitumen. As the city specifies 10 to 13 per cent. bitumen, the amount of new asphaltic cement was reduced somewhat. He is of the opinion that the costs of laying asphalt using old material can be greatly

[1] *Engineering Record*, Jan. 24, 1914.

reduced in the summer season with a more efficiently organized crew.

The unit costs per square yard of paving actually covered were: Coal, 2.5 cts.; asphalt (standard paving), 3.4 cts.; crushed stone (used 3 days only), 0.7 cts.; marble dust, 0.2 cts.; total for materials 6.8 cts.; plant and truck, 10.8 cts.; laying 20.3 cts.; undistributed, 4.8 cts.; total labor 35.7 cts.; grand total, 42.5 cts.

CHAPTER XVII

SELECTION OF TYPE OF SURFACE FOR RURAL HIGHWAYS

The choice of the type of surface for the improvement of a public highway requires an analysis of many factors that have a bearing on the ability of the type of construction selected to meet the needs of the community in which it is to be built. Some of these factors are not susceptible of exact tabulation, and their bearing on the problem is a matter in which the only guide is the engineer's judgment and experience. Others have an effect that has been definitely established by experience and observation, so that their relation to the design is well understood and is generally recognized. The following are the more important factors, and those encountered in the ordinary community, but others peculiar to individual roads sometimes modify the design in an important manner.

THE TRAFFIC CENSUS

The facts in regard to traffic are sometimes sufficiently well understood from general observation to eliminate the necessity for taking the traffic census. Such general data cannot be depended upon, and where costly permanent improvement of important highways is to be undertaken, the traffic census is a preliminary that should never be omitted. Its value is too often underrated and, in general, is little understood by American engineers, but it has had long and widespread use in England and in Continental Europe.

Not only is the traffic census invaluable as an aid to the selection of the type of surface and the design, but if continued after a road is improved it gives valuable information as to rate of wear and maintenance costs per ton of traffic. Without these, scientific and economical administration is impossible.

Present Traffic.—The gross amount of traffic is one of the first things to be determined. This is primarily of importance as affecting the width of the road, but also has a bearing on the kind of surface to be provided, although other factors are also

of significance in that respect. It is undesirable for a vehicle to turn off a hard surface too frequently in passing other vehicles. Probably with earth side roads this should not occur oftener than about five times per mile, and if the amount of traffic is such that the average number of passings per mile exceeds five, the road should be provided with some reasonably stable type of side road for the vehicle to turn out on. If the average number of passings exceeds about ten per mile for each vehicle using the road, then the side road will receive so much traffic that it must be about as well constructed as the main trackway, or, in other words, the main trackway should be wide enough to permit two vehicles to pass and still remain on it. The amount of passing can only be determined after the number and character of the vehicles using the road has been ascertained together with the distribution of the traffic during the day.

Kinds of Traffic.—The kinds of vehicles and the weight of the individual loads have a direct bearing on the type and thickness of the surface that will be required. If the traffic consists of miscellaneous hauling of farm products and of light vehicles and automobiles for pleasure driving such as may be encountered in a rural community, that is a condition which presents a definite problem in highway design. In other instances the traffic may include in addition to this miscellaneous traffic, many heavy horse-drawn trucks with loads ranging up to 6 tons and motor trucks with loads of 8 to 10 tons. The problem thus presented is also definite but requires a different design from the one first described. These illustrations are two out of a large number of sets of conditions that are encountered, and emphasize the importance of learning by investigation just what are the requirements before deciding upon the design of the surface.

Peculiarities of Traffic.—On many roads there are peculiarities of traffic that affect the choice of type very materially. The traffic is much heavier at certain times of the day or at certain seasons of the year than at other times in some communities. Not infrequently the travel on rural highways is nearly all toward town in the morning and away from town in the afternoon, and, although a great many vehicles might use the road each day, a single-track surface would suffice because of this peculiarity. Roads used for pleasure driving will have heavy traffic in the summer, especially at week ends, which will not show up in a traffic census taken in the winter or spring. This must be

taken into account and the census must be planned so as to bring out any peculiarities that may exist.

The Traffic Census.—All of these facts in regard to present traffic must be determined as the first step in the choice of the type of road surface to build. Some of them are at once apparent to an experienced engineer who makes a careful inspection of the road, and some can only be determined by taking a traffic census.

The traffic census to have the greatest accuracy should be taken by an experienced observer, but very good results can often be obtained by employing a resident convenient to the road if a suitable form is furnished for his use, even though he is inexperienced. The form can be so clear and so easily filled in that few errors are probable. Since the traffic is apt to vary at different hours of the day, on different days of the week and during different seasons of the year, the traffic census ought to be taken for a year if a complete record is desired. Records need not be made daily during this period, but may be taken for a few days at a time at intervals throughout the year. It is conceded that for important roads the traffic census should always be taken for a considerable period prior to deciding on the design for the road. On roads of lesser importance the information that would be given by the traffic census may be obtained as nearly as possible by expert inspection, but considerable care and judgment are necessary for such inspection work, if the results are to be of any value.

Present traffic on a highway is not necessarily an indication of the amount that will use the road when it has been improved. It does serve as a basis for making a scientific estimate of the traffic that will use the road during its probable life, and that is the great value of the traffic census from the standpoint of design. It does have a distinct additional value as basis for the comparison of roads actually in service and as a check on the accuracy of the assumptions made when the road was designed. For these latter purposes the census must extend over a series of years.

Traffic Zones.—In order to estimate the probable increase in traffic, it is desirable to ascertain as nearly as may be the extent of the territory that will be served by an improved road. It is known that when a good road is built out from a town, the general effect is to decrease the apparent distance from any point in the territory served by the road to the town, and consequently the territory tributary to the town is increased. The amount of the increase will depend upon many factors, such as the character of

agricultural activities, the topography, the road-building activities in the vicinity of nearby towns and the market facilities of those towns. All of these when analyzed make the mapping of traffic zones possible as a preliminary to highway design. The traffic zone is usually understood to be the area of the rural community that will be served by a main highway and its branches. All of the traffic originating in the zone is expected under normal conditions to use the improved highways of the zone for business purposes and to a large extent for pleasure driving. Near the market center from which the roads radiate, the territory in the zone will be confined to a narrow strip along each side of the road. Farther out from the city the road and its branches will serve a larger area so that the outline of the zone usually is the familiar balloon shape.

Traffic zones will change with the extension of the road or with the extension of roads from nearby cities. They serve as a valuable guide in the selection of the type of surface needed and in estimating the increase in traffic to be provided for. The traffic zone also indicates the adequacy of the proposed system of main roads, by showing the extent of the territory served and the convenience of the proposed system to the residents of the outlying parts of the district.

The statistics relative to traffic will in the ordinary community inadequately represent the conditions to which an improved road will be subjected within a few years after it is opened to public use. Experience shows that when a road is improved the travel on it immediately becomes much larger than it was before. Ultimately, when all the main roads in the community have been improved, the travel will be equalized, but in the meantime the first sections built will have been subjected to much greater traffic than would be shown by a traffic census taken before the roads were improved.

ANALYSIS OF THE TRAFFIC CENSUS

The object of the traffic census has been set forth, and it now becomes pertinent to note how the traffic census is taken and the analysis by which the various deductions are obtained from the tabulated census data.

The width of road is dependent upon the gross amount of traffic that will probably use the road, or the frequency with which vehicles must turn out in passing. Knowing the number

of vehicles of each class and the probable average speed of travel, it is easy to compute the average number of passings per mile. If this number exceeds five and is less than ten, the side road probably should be of fairly substantial material so as to sustain this passing. If the number of passings per mile exceeds about ten, the road should doubtless be double-track width.

The type of surface is dependent not only on the amount of the traffic but the character and weight of the individual loads. In the last analysis the two important factors are total number of vehicles of each class and the load on the pavement per foot or yard of width or some similar designation that will have the same significance.

Various methods of taking the traffic census are employed, and forms convenient for recording the number of vehicles are prepared. These differ in detail and in the classification of the vehicles. The following examples serve to illustrate a few of the methods.

THE COMMONWEALTH OF MASSACHUSETTS

MASSACHUSETTS HIGHWAY COMMISSION

TRAFFIC RECORD

1912

STATION NO

TOWN-CITY

DATE

LOCATION OF STATION

(AT OR NEAR STA . . . MHC NOTATION)

KIND OF VEHICLE	7 AM TO 9 AM	9 AM TO 11 AM	11 AM TO 1 PM	1 PM TO 3 PM	3 PM TO 5 PM	5 PM TO 7 PM	7 PM TO 9 PM	TOTALS
SINGLE HORSE { LIGHT VEHICLE								
SINGLE HORSE { HEAVY VEHICLE								
TWO OR MORE HORSES { LIGHT VEHICLE								
TWO OR MORE HORSES { HEAVY VEHICLE								
AUTOMOBILE { RUNABOUT								
AUTOMOBILE { TOURING CAR OR WAGON								
MOTOR { TRUCK OR OMNIBUS								
TOTALS								
WEATHER CONDITIONS								

SIGNATURE OF OBSERVER

OBSERVER WILL NOT WRITE IN THIS SPACE

Form used by Massachusetts Highway Commissions.

FORM USED BY MILWAUKEE COUNTY, WISCONSIN

	12–1 a m	1–2 a m	2–3 a.m	etc
Touring cars				
Roadsters and runabouts				
Auto trucks				
Motorcycles and bicycles .				
Single-horse vehicle				
Light team				
Heavy team				
Pedestrians on walk or road .				

This information is variously tabulated for purposes of comparison but such tabulation must show weight as well as quantity and the following are examples employed for the purpose:

TRAFFIC CENSUS FORM RECOMMENDED BY SPECIAL COMMITTEE A. S. C. E.

Horse-drawn vehicles	Number empty	Number loaded	Est max. load per inch of width of tire in lb.	Passenger vehicles
One-horse vehicles . . .				
Two-horse vehicles. .				
Three-horse vehicles .				
Four-horse vehicles . .				
Five-horse vehicles.				
Six or more horse vehicles. . .				
Motor-vehicle traffic				
Motorcycles				
Motor runabouts				
Motor touring cars (4 or 5 seats)				
Motor touring cars (6 or 7 seats)				
Motor wagons or drays				

It is exceedingly important to use the proper factors in arriving at the weights of the various kinds of vehicles and tables 27 and 28 show practice in England and in the United States.

MASSACHUSETTS HIGHWAY COMMISSION RECORDS. BOSTON SOUTH SHORE ROAD, STATION NO. 403, WIDTH 32 FT.

Motor vehicles	Average number per day	Assumed average, weight in tons	Total tons per yard of width, per day
Runabouts..	114.0	1 43	15 3
Touring cars.	467 0	2 23	97 6
Trucks........ . . .	38 5	6.25	22 6
Horse-drawn vehicles			
Light vehicles, one-horse	45 0	0 36	1 5
Heavy vehicles, one-horse	216.5	1 12	22 7
Light vehicles, two or more horses	0 5	0 54	.
Heavy vehicles, two or more horses .	104 5	2 46	24 1

TABLE 27.—UNITED STATES OFFICE OF PUBLIC ROADS CATEGORIES

	Tons
1. Loaded one-horse wagon	0 88
2. Unloaded one-horse wagon . . .	0 28
3. Loaded two-horse wagon	1 57
4. Unloaded two-horse wagon .	0 47
5. Loaded four-horse wagon.	3 88
6. Unloaded four-horse wagon (gears)	0 54
7. One-horse pleasure vehicle. .	0 28
8. Two-horse pleasure vehicle .	0 47
9. Rubber-tired horse vehicle..	0 28
10. Saddle horse...	0 50
11. Motorcycle...	0 20
12. Excessively heavy vehicle .	3 94
13. Motor runabout .	1 68
14. Motor touring car.	2 00
15. Loaded motor dray.	2 43
16. Unloaded motor dray .	1 23
(Draught horses).	0 50

TABLE 28.—ENGLISH ROAD BOARD CATEGORIES

	Tons
1. Heavy vehicle, one-horse.	1 25
2. Light vehicle, one-horse	0 40
3. Heavy vehicle, two-horse (or more)..	2 50
4. Light vehicle, two-horse.	0 60
5. Horse lead or driven. . ..	0 50
6. Motorcycles..	0 13
7. Omnibuses, two or more horses..	3 00
8. Motor cars.	1.60
9. Motor van, covered	2 50
10. Horses, drawing vehicles......	0.50

Having obtained the traffic information and made suitable allowances for the probable increase, the type of surface necessary is to be selected in accordance therewith. No great amount of data is available for use in making the selection, but the following table is probably one of the best that has been prepared:

TABLE 29.—AVERAGE DAILY TRAFFIC LIMITS IN MASSACHUSETTS

Table showing results of observations of traffic on different types of road surfaces in Massachusetts. Standard road, 15 ft in width, gravel or waterbound macadam, 5 or 6 ins in thickness, with adequate drainage and proper foundation, with 3 ft gravel shoulder on each side.

Type of surface	Light teams, carriages, wagons	Heavy teams, one-horse	Heavy teams, two or more horses	Automobiles
A good gravel road will wear reasonably well and be economical with	50–75	25–30	10–15	50 to 75
Needs to be oiled with .	50–75	25–30	10–15	Over 75
Oiled gravel, fairly good, heavy cold oil, ½ gal to the sq yd applied annually with..	75–100	30–50	20	500 to 700 or more
Waterbound macadam will stand with	175–200	175–200	60–80	Not over 50 at high speed
Cold oil or tar will prove serviceable on such macadam with	175–200	175–200	60–80	50–500
Macadam will then stand, but the stone wears, of course, with. .	175–200	175–200	60–80	500 or more
Waterbound macadam with hot asphaltic oil blanket will be economical with . . .	100–150	50 75	25–30	1,500 and more with fewer teams
And stand at least				50 trucks
But will crumble and perhaps fail with over (On narrow tires, ice, farm and wood teams, etc)	150	75	30	
Waterbound macadam with a good surface coating of tar (½ gal to the sq yd) will stand with (But requires to be recoated annually with ¼ gal of tar per sq yd)	100-150	50–75	25-30	1,500 or more

It is assumed that all road surfaces are kept constantly patched, that before applying bitumen the road surface is cleaned and patched, and the bitumen covered with pea stone and sand or gravel and kept covered so that it never picks up.

TABLE 30.—SUMMARY EMPLOYED BY BUREAU OF ENGINEERING, BUFFALO

Direction	Street	Location	Width of pavement	Average daily tonnage per 14 hr	Average tonnage per hour	Average daily tonnage per foot of width	Average number of vehicles per 14 hr.	Average number of rigs	Average number of automobiles	Average tonnage per rig

TABLE 31.—RECAPITULATION, CITY OF CHICAGO

Traffic census in "loop" district							Horse-drawn vehicles			Motor-driven vehicles									
Traffic observed																			
Day	Date	On	Between	And	Direction traffic bound	Hours of observation	Number of wagons of all description	Number of carriages	Number of buggies	Number of auto trucks, all kinds	Number of two-seated autos	Number of four or more seated autos	Number of street cars	Totals	Average number of vehicles per hour	Per cent. of horse-drawn vehicles	Per cent of auto-trucks and automobiles	Per cent of street cars	Table number
Tuesday	July 13	Rush	Street	Bridge	North	8	1398	12	37	612	1448	4948	. .	8446	1005 75	17 026	82 974		15
Tuesday	July 13	Rush	Street	Bridge	South	8	1102	11	32	247	886	2876	. .	5154	644 25	22 22	77 78	.	15
Tuesday	July 13	Michigan St.	E. So. Water St	River St.	North	8	292	12	25	167	825	3133	.	4454	556 75	7 39	92 61		14
Tuesday	July 13	Michigan St.	E. So Water St	River St.	South	8	343	5	21	167	470	3526	.	4532	566 5	8 15	91 85	.	14
Monday	July 26	River St	Michigan St	Wabash Av	N E	9	1008		8	124	32	204	. . .	1376	172 0	73 837	26 163		12
Monday	July 26	River St.	Michigan St.	Wabash Av	S W.	9	1096		1	247	62	148	. .	1554	172 66	70.59	29 41		12

It is highly desirable to have at hand a tabulation showing the wearing value of the several types of pavement in terms of tons of traffic per yard of width, and the aim of the traffic census should be to adduce such data.

The following table is such a tabulation:

TABLE 32.—TRAFFIC STATISTICS FROM SHEFFIELD, ENGLAND

Type	Traffic in tons per yard with per year	Initial cost	Probable life, years	Cost per square yard per year
6-in. granite block. . .	73,180	$3.66	27	$0.15
Redwood blocks .	44,983	2 40	14	0 23
Tar macadam No. 1.	69,762	0 66	21	0 12
Tar macadam No. 2.	35,939	0 46	21	0 06

TABLE 33.—TRAFFIC STATISTICS FOR LIVERPOOL, ENGLAND

Type	Life in years	Life tonnage per yard width	Cost per square yard	Total maintenance per square yard including interest	Ton miles a yard width for 1 ct	Cost of maintenance per 100 ton-miles traffic
6-in. granite block	18	9,432,000	2 40	0 175	17	0 06
Soft wood	18	3,672,000	2 04	0 15	8	0 13
Pitch macadam	11	1,320,000	0 72	0 066	10	0 096
Tar spray macadam	2	240,000	0 24	0 12	5 7	0 18
Water-bound macadam	1	120,000	0 18	0 18	3 8	0 264

OTHER FACTORS INFLUENCING SELECTION OF TYPE

Increase in Traffic.—It becomes highly important to estimate the probable increase in traffic when a road is improved. This increase may result from a diversion of traffic from other roads which are parallel or lead in the same general direction as the one to be improved. A study of such roads and the amount of traffic that may be diverted from them is a guide in determining the probable increase in traffic. This becomes very significant if a nearby parallel road is a logical through route between populous centers, because a detour of a few miles is not a serious deterrent to tourists who are traveling across country and they will usually take the route that insures the greatest comfort and speed.

The increase in traffic may come from new industries that are purposely located on the improved road. Such a development cannot ordinarily be foreseen and yet may prove to be a most important factor in the maintenance of the road.

Another very important factor is the probable change in character of traffic. It is assured that as the highways of a community are improved, the transportation methods will undergo a change. Heavier loads will be hauled and in many instances motor vehicles will be substituted for horse-drawn. This is particularly true of the roads in the vicinity of the larger centers of population. It is doubtful if even the most visionary predictions of these developments during a decade will be anywhere near up to the actual facts as time reveals them.

Not only will traffic change due to new methods of transportation, but new agricultural methods are sure to result. Dairying, truck farming, and similar activities will be substituted for farming methods requiring less frequent use of the highways.

Probably no factor has had so much bearing on the desire for road improvement as the development of the motor vehicle used for pleasure, and its use has just begun. Without doubt the automobile and motor truck will become much more widely used in the rural communities as time goes on, and the number of city-owned cars using the highways is also certain to increase enormously. This most important fact must be recognized in deciding upon the type of road.

Provision for Maintenance.—The provision for maintenance in the community where the road is to be built has a bearing on the type of road that is to be built. The maintenance work may be done under skilled supervision, but the unit of control may be so large that only seasonal maintenance can be expected, in which circumstance a type of road must be selected that will have reasonable life under such conditions.

If the maintenance is under unskilled supervision, there are very few types of road that can be expected to remain in good condition for any length of time. The most durable type possible to construct could be recommended in such circumstances, thus relying on the durability of the surface to obviate the necessity for maintenance except at long intervals. The other alternative would be to build the cheapest form of road, such as gravel, which can be repaired by an unskilled superintendent with fair results.

If a road is to be a part of a system which is regularly inspected and maintained under constant and skilled supervision, then the type of road may be selected without any limitations from the standpoint of maintenance methods.

Local Materials.—If local materials of any kind are available, that will be a factor to consider before choosing the type of road. The kind, quality, and cost of local materials relative to the same properties of shipped-in materials, will determine which is ultimately the most economical. If the local materials are of poor quality even though low in price, it will often pay to bring in more durable materials of another kind rather than to utilize the local materials and construct a road that will be expensive to maintain.

Foundations.—When the soil upon which the road is to be built affords a good foundation, no modification of the type will be made necessary by a consideration of this factor, but in those instances where poor foundation is encountered which cannot be corrected by drainage, a type of roadway must be selected that will distribute the load sufficiently to secure stability. Such foundations are encountered occasionally.

The following table gives the results of some French experiments on the transmission of pressure through macadam to the subgrade. The test was made with a wheel load of 4 tons with a 5½-in. tire.

TABLE 34.—SHOWING TRANSMISSION OF PRESSURE THROUGH MACADAM

On macadam alone:					
Thickness of crust, inches	1 97	3 94	5 91	7 87	11.81
Pressure on subsoil, pounds per square inch	102 50	47.70	27 40	17.40	9 10
On Telford foundation alone:					
Foundation thickness, inches			5 91	7.81	11.81
Pressure on subsoil, pounds per square inch			56 00	37.40	20 70
On combined foundation and macadam:					
With foundation thickness of, inches		5 91	7 87	9 84	11 81
3.94 in. of stone, pressure on subsoil, pounds per square inch		19 30	14 70	12.60	10 20
5.91 in. of stone, pressure on subsoil, pounds per square inch		13 20	10 90	9.10	7 70
7.87 in. of stone, pressure on subsoil, pounds per square inch		9.70	8 20	6 80	6.10

"The pressure on the subsoil through a 12-in. bed of simple macadam is apparently the same as the pressure through a 6-in. bed of macadam laid over a 10-in. stone foundation. A good soil well drained will safely withstand a pressure of 30 lb. per square inch.

"It is considered that poor soil required at least a 12-in. macadam layer or its equivalent.

"The pressure transmitted by well-constructed gravel will be about the same as with macadam of equal thickness. The pressure will be much more widely distributed by concrete monolithic foundations and will be relatively much less per square inch in consequence."

Aesthetic Considerations.—Some attention should be paid to the appearance of a highway, and when the road lies in thickly populated suburban territory, dusty, sticky or noisy surfaces should be eliminated when possible. Every effort should be made to preserve any natural beauty of the roadside and to encourage the growth of shrubs and harmless wayside grasses. Apparently the washings from none of the commonly used materials affect the plant life, but excessive dust is a menace to plant beauty, and is to a small extent detrimental to plant life.

Making the Selection.—The selection of the type of surface suitable for a known set of conditions involves a knowledge of the characteristics and the cost of the various types of surfaces and the materials necessary in their construction. These factors will be discussed in succeeding chapters.

The financial considerations are purposely left for discussion in connection with the selection of type of pavement surface, since better data on the costs and length of useful life of types of pavements are available than on costs and useful life of the same surfaces when employed on rural highways.

CHAPTER XVIII

SELECTION OF TYPE OF PAVEMENT SURFACE

The selection of the type of pavement involves the consideration of many factors that need not be taken into account in selecting the surface for a rural highway. Cost and durability, factors that are of such importance in selecting the type for rural highways, also weigh heavily in the selection of street paving, but many other things must be considered also. It is perhaps unfortunate that many cities and especially those having a population of 10,000 or less, select their pavements without having made any scientific study of the question, the result being that pavements entirely unsuited to conditions are constantly being constructed to the great loss of the property owners who pay for the improvement. This condition is occasioned by two commonly recognized weaknesses in our American system of administration of highway construction.

First of all the administration is political rather than technical, with ever changing personnel, so that continuity of policy and systematic records of the service value and cost of maintenance of pavements have not been possible.

In the second place American communities are developing with phenomenal rapidity so that conditions of traffic in the cities do not remain constant long enough to permit conclusions to be drawn without the most minute records and these have not been kept except in a very few cities.

It is not at all agreed as to what qualities in a pavement should be considered as of most importance in any case. A great deal depends upon the individual making the selection, since some qualities weigh more heavily with one person than they do with another. The tendency, however, is toward an exact analysis, regardless of personal preferences.

In general the problem of selection of the type of pavement resolves itself into a special study for each case, yet a great many streets have identical characteristics and a type suitable to one will be suitable for all. The following discussion of the characteristics of pavements will serve to indicate in a general way the factors that should be taken into account.

Durability.—Obviously the life of any type of pavement is dependent upon the class and amount of traffic to which the street is subjected, and the character of workmanship secured in its construction. There are not as yet any considerable exact data as to the wear-resisting properties of the various types of pavement, in terms of tons of traffic per foot of width or any similar unit. To be of value, such data should be susceptible of application to a type of pavement when the character of

Type of pavement	No. of cities reporting	Maximum life reported	
		Business street	Residence street
Sheet asphalt	14	15 years or more	
	32	10 to 14 years	
	18	5 to 9 years	
	2		25 years or more
	15		20 to 24 years
	30		15 to 19 years
	14		12 to 14 years
	12		10 to 11 years
Brick	3	25 years or more	
	14	10 to 24 years	
	34	15 to 19 years	
	17	12 to 14 years	
	20	10 to 11 years	
	10	less than 10	
	6		30 years or more
	25		25 to 29 years
	16		20 to 24 years
	22		15 to 19 years
	12		10 to 14 years
Wood block	1	30 years or more	
	1	21 to 25 years	
	2	16 to 20 years	
	4	11 to 15 years	
	3	10 or less	
	2		26 to 30 years
	1		21 to 25 years
	4		16 to 20 years
	1		15 or less
Bitulithic and tar treated of various kinds	4	15 years or more	10, 15 or more
	12	10 to 14 years	13, 10 to 14 years
	6	5 to 9 years	5 less than 10.
	3	less than 5	

the materials, and the thoroughness with which the construction was carried out, were known.

Illustrating the extreme variation of estimates of life of pavements in American cities the foregoing table is given.

Slipperiness.—This characteristic is distinguished from the condition of surface that gives a poor foothold for horses although the two characteristics often go together, and will be considered together in the comparisons made here. The condition of slipperiness is of significance to motor-driven traffic and is a characteristic of most sheet pavements, and of wood-block pavements and to some extent of stone-block pavements, when they are wet or frosty. Skidding and poor traction are the result of slipperiness and these introduce an element of danger into the use of pavements having this property.

Character of Foothold for Horses.—This property depends upon there being joints or some roughness to afford foothold. Sheet asphalt affords rather poor foothold when wet and the asphaltic concretes are much the same but more so when finished with the seal coat of asphaltic cement and stone chips than when finished without such a seal coat. Granite blocks wear to a polished and rounded surface and each block is slippery when wet but the joints between blocks serve to give shod horses a foothold.

Appearance.—In some locations the appearance of the pavement will be of no significance, in others it is desirable to have a pavement that will harmonize with the surroundings. Several factors combine in the appearance of the pavement such as color, reflection of light, the presence or absence of joints between the units of the surface, irregular cracks and the texture of the surface.

Dust.—Dust in appreciable quantities resulting from the wear on a pavement surface, is an accompaniment of excessive wear and is particularly a characteristic of macadam and gravel surfaces. It is undesirable for city pavements in any location.

Sanitariness.—This is a characteristic of minor importance since the types suitable for most city streets do not differ greatly in sanitary qualities. If the type is such that street liquids can penetrate the surface and produce odors and breed disease it is undesirable, but no high-class pavement is of such a nature.

Susceptibility to Cleaning.—This characteristic is important because it is a factor in the cost of keeping the street clean, and

because a type that is hard to clean or expensive to clean may become insanitary from neglect. The ease with which a street may be cleaned depends upon the texture of the surface and the number of joints or cracks in the surface.

Noise.—The degree of the noise of traffic on a street depends very largely on the character of the pavement. This frequently becomes an important factor in the selection of type. Under modern traffic conditions in our cities it is very desirable to eliminate noise as much as possible. Undoubtedly the construction of the less noisy pavements will become more and more general for congested city districts.

Tractive Resistance.—This factor is of minor importance since the high-grade pavements do not differ greatly in tractive resistance. Taken in connection with other characteristics it may be the determining factor in the selection in some instances, but in general it has little bearing on the selection of type. It would be a more significant factor if the amount of tractive resistance for the several types of pavements were more variable. No very reliable data on tractive resistance are available but the following composite table indicates average values.

Table 35.—Average Tractive Resistance of Surfaces[1]

Surface	Tractive force per ton
Earth packed and dry	100
Earth dusty	106
Earth muddy	190
Sand loose	320
Gravel good	51
Gravel loose	147
Cinders well-packed	92
Oiled road—dry	61
Oiled road—wet	108
Macadam—very good	38
Macadam average	46
Sheet asphalt	38
Asphaltic concrete	40
Vitrified brick—new	56
Wood block—good	33
Wood block—poor	42
Cobblestone	54
Granite tramway	27
Asphalt block[2]	52
Granite block[2]	47

[1] *Municipal Engineering*, January, 1913.

[2] Other source, not in original table.

Maintenance.—Some types of low-cost pavement might prove economical under constant maintenance, but in many locations the continual disturbance of the street for making repairs and the interference with traffic make it undesirable to employ such surfaces. Ease of maintenance so that streets can be repaired quickly with little disturbance to traffic is desirable.

The characteristics enumerated above are the ones of greatest significance in the selection of type for which purpose the relative values of the several characteristics is of more use than is an arbitrary valuation of each. The following table is a comparison of these characteristics for each of the common types of pavement assuming each to be in first-class condition. No. 1 indicates the first choice so far as each characteristic is concerned and higher number a lower degree of desirability.

TABLE 36.—COMPARISON OF PAVEMENTS

Type	Initial cost	Durability	Sanitary qualities	Noiselessness	Slipperiness	Dustlessness	Appearance	Ease of cleaning	Tractive resistance	Ease of maintenance
Gravel	1	8	6	3	2	4	8	7	7	5
Water-bound macadam	2	9	6	3	2	4	9	7	7	4
Bituminous macadam	3	7	3	2	5	1	3	4	4	6
Portland-cement concrete	4	6	1	5	3	2	5	2	1	4
Stone-filled sheet asphalt	6	5	1	1	7	1	1	1	4	2
Sheet asphalt	7	5	1	1	8	1	1	1	4	2
Asphalt block	8	5	3	1	5	1	1	1	4	5
Vitrified brick; grouted	9	4	4	5	3	2	4	3	1	6
Wood block	10	3	2	1	4	1	2	1	2	1
Sandstone block	11	2	5	4	1	3	6	5	5	4
Granite block	12	1	5	6	3	2	7	6	6	4
Bituminous concrete	5	5	1	1	6	1	1	1	3	3

FACTORS DETERMINING SELECTION

The relative characteristics of pavements are of value only as a guide in selecting the type for known conditions. For some locations one characteristic is much more important than it is for other locations, and sometimes the selection must be made entirely on the basis of one or two desired characteristics. Just what characteristics will be the determining ones in the selection

will depend upon the traffic on the street and the location of the street and its surroundings.

Location.—The location in the city and the character of the abutting property are first to be considered. Obviously some things would be pertinent for a street in a congested business district that would not apply in a warehouse or freight-house district, although the traffic might be very much the same. In the first instance, appearance, absence of noise, sanitariness, ease of cleaning, and ease of repairing, would be important factors to consider in addition to freedom from slipperiness and durability. In the latter case durability and freedom from slipperiness and ease of repairing would be the principal characteristics desired. Generally it would be unnecessary in either instance to consider initial cost.

For a boulevard system, appearance, sanitariness, ease of cleaning, durability and freedom from noise would be considered.

For high-class residence streets the factors considered for a boulevard system would be pertinent.

For poorer residence districts initial cost would be the most important consideration. Noiselessness, sanitariness, ease of cleaning and dustlessness would also be important.

Traffic.—The traffic is always a very important consideration in selecting the type of pavement. The traffic census and its analysis is explained on page 330.

TABLE 37.—RELATIVE IMPORTANCE OF CHARACTERISTICS IN SELECTING PAVEMENTS FOR LARGER CITIES

Order of importance	Office and retail district	Wholesale district	Warehouse and dock or railroad district	Boulevards, high-class residence district	Poorer residence district
1	Noiselessness[1]	Durability[1]	Durability[1]	Noiselessness[1]	Cost
2	Appearance	Noiselessness	Slipperiness	Appearance	Durability
3	Durability	Slipperiness	Tractive resistance	Slipperiness	Maintenance
4	Sanitariness	Ease of cleaning	Ease of maintenance	Durability	Dustlessness
5	Ease of cleaning	Sanitariness	Cost	Ease of cleaning	Sanitariness
6	Slipperiness	Maintenance	Ease of cleaning	Cost	Ease of cleaning
7	Maintenance	Tractive resistance	Sanitariness	Sanitariness	Appearance
8	Tractive resistance	Cost	Noiselessness	Maintenance	Tractive resistance
9	Cost	Appearance	Appearance	Tractive resistance	Slipperiness

The foregoing table indicates in order the relative importance of the several characteristics for various classes of streets in the larger cities (50,000 population and upward).

TABLE 38.—RELATIVE IMPORTANCE OF CHARACTERISTICS IN SELECTION OF PAVEMENT FOR SMALLER CITIES

Order of importance	Business streets	Boulevards and high-class residence streets	Poorer residence streets
1	Durability[1]	Cost[1]	Cost
2	Cost	Durability	Durability
3	Noiselessness	Noiselessness	Dustlessness
4	Appearance	Appearance	Ease of repairs
5	Ease of repairs	Ease of cleaning	Ease of cleaning
6	Ease of cleaning	Ease of repairs	Sanitariness
7	Sanitariness	Slipperiness	Noiselessness
8	Slipperiness	Sanitariness	Appearance
9	Tractiveresistance	Tractiveresistance	Slipperiness

Apparently it is not possible to lay down exact rules for the selection of the type of pavement because of the great variety of conditions that are encountered. Several of the types are so nearly alike in their more important characteristics that the final selection may be based principally on cost which is a variable depending upon locality.

Cost of Pavements.—In discussing the cost of pavements it is customary for the layman to take only the initial cost into account, rather than the annual cost for the life of the pavement. This is wholly illogical because the ratio of the annual costs may be very different from the ratio of initial costs. It should not be inferred that the pavement having the lowest annual cost is always the best since the cost may be in part increased by the cost of keeping the particular type clean or it may be based on effective and continual expert maintenance, a condition not found in many cities of less than 50,000 population. Obviously the initial cost, which is a variable in the cities of America, is a factor in the annual cost. The first cost can always be determined for any locality with a considerable degree of accuracy and the annual cost can then be estimated for comparative purposes.

Annual Cost.—Annual cost is a somewhat illusive item and one may easily be misled in calculating it. It should be assumed that the construction of a pavement represents a justifiable investment

[1] Other requirements eliminate the dusty types.

upon which the community will receive adequate returns. These returns are not susceptible of exact valuation, consisting in part of increased facility of communication, increased comfort of travel, better appearance, better returns from abutting property and similar clearly defined benefits. Having invested money in a pavement, these returns are accepted in lieu of interest on the money so invested, and since money is willingly so invested it may be assumed that the return is adequate to compensate for the loss of interest. As the pavement is used it must be maintained and the cost thereof is a direct contribution for insuring that the pavement will have normal life. Interest should never be charged against a pavement in a comparison unless at the same time the direct return is considered and evaluated, which is impossible. A high interest charge would be necessary for a pavement of high initial cost but such a pavement might produce a high economic return because of low tractive resistance and general usefulness. The pavement of low initial cost would be charged with a low interest but might also represent a lower economic usefulness. Obviously it is exceedingly difficult to evaluate the relative usefulness and for that reason interest on initial investment will not be considered in the comparisons made herein.

Economical Life.—A pavement will eventually wear to a condition where it has ended its economical life. It must then either be rebuilt in entirety or be resurfaced. When it reaches this stage it will likely have some value left in it. It may have a foundation suitable for a new surface or the entire pavement may be covered with a new wearing surface. Some of the materials of the old surface may be utilized in the new. In determining the economical life of a pavement surface the two factors that need to be taken into account are the total cost of maintenance and the cost of renewal of the surface. The base, curbs and drainage structures will ordinarily last so long a time that their cost is negligible in determining economical life, and has no bearing on comparison of surfaces.

As the pavement ages, the cost of maintenance will increase and consequently the average cost of maintenance per year will gradually increase. The quotient obtained by dividing the initial cost of the surface by the years of life will decrease as the pavement increases in age. At first this quantity will be greater than the average annual cost of repairs so that the sum of the two

quantities will decrease from year to year. Eventually, however, the average annual cost for repairs will increase more rapidly than cost divided by years of life will decrease and the sum of the two will begin to increase each year. Hence a pavement has reached its economical life when

$$\frac{\text{total cost of repairs to date} + \text{cost of renewal of surface}}{\text{years of life}}$$

becomes a minimum.

Residual Value.—It has been previously pointed out that a pavement has some value left in it at the end of its economical life. The base may be used again, or the pavement as a whole may be used as a base for a new surface. Some of the materials of the worn-out surface may be usable. As an example, the old surface material from a sheet-asphalt pavement may be utilized for the binder course for the new pavement; old stone blocks may be redressed and reset. The residual value is the difference between the initial cost of the original pavement and the cost of a new surface that will be suitable for the pavement at the end of the economical life of the first surface.

That the various factors entering into the annual cost and especially the wear of traffic are susceptible of fairly exact analysis has been demonstrated by British highway engineers and some excellent estimates have been made by American engineers and the following tables are inserted as indicating the kind of information that should be available when selecting the type of pavement.

TABLE 39.—SHOWING ESTIMATED ANNUAL COST OF PAVEMENTS FOR A PERIOD OF 40 YEARS[1]

Type	Life, years	First cost	Annual cost per square yard
Macadam.................. ..	10	1.00	$0 179
Granite block, grout filler	20	3.25	0 200
Brick, grout filler	15	3.00	0.240
Bitulithic..	10	2.65	0.284
Wood blocks.	15	3.75	0 292
Tar macadam.	10	1 25	0 296

[1] Engineering and Contracting, Dec. 20, 1911.

For a Period of 50 Years[1]

Type	Initial cost	Average cost per year for 50 years	Assumed life
Granite block . . .	3 50	0 27	25
Asphaltic	2 00	0 164	18
Wood block.	3 50	0 274	20
Brick.	2 25	0 199	15

Recapitulation.—The selection of types of pavement involves the following analysis, as has been already outlined.

1. The selection of those types that possess physical characteristics suitable to the location.

2. The elimination from pavements complying with the requirements (1) of those that obviously do not have the necessary durability.

3. The elimination of pavement types surviving the selection in (2) for which suitable materials cannot be obtained at reasonable cost.

4. An estimate of the economical life of each type remaining under consideration is then made. This estimate will be possible only after an analysis of traffic on the street to be paved.

5. A financial comparison of the types remaining under consideration is made, based on the probable initial cost in the community and the following factors would enter into such a tabulation:

(*a*) $\dfrac{\text{Initial cost—residual value}}{\text{economical life}}$

(*b*) Average annual cost of maintenance.

(*c*) Average annual cost of cleaning.

[1] Tillson's Street Pavements and Paving Materials.

CHAPTER XIX

THE DESIGN OF PAVEMENTS

The primary requirement for a pavement is that it serve as a trackway for vehicles, and this fact must be given first consideration in the design. The convenience and comfort of the user are to be insured regardless of other factors that enter for secondary consideration.

Other things are often of importance and have considerable bearing on the design. These are drainage of abutting property, appearance, effect on value of abutting property, cost and problematical future traffic needs.

Grades.—The principles discussed as applying to the grades suitable for rural highways should apply equally to grades on streets, but topographical features often limit the application of those principles, and a few general rules have been gradually established to guide in the determination of the grade line for streets.

I. The top of the curb on residence streets should always be lower than the lawns or parkings on either side. It is usually necessary to carry storm water and water resulting from melting snow from residence property to the pavement in order to dispose of it. This requires that the sidewalk shall slope slightly toward the curb and that the parking between the walk and curb line shall also slope toward the curb.

Sometimes the drainage may be carried to a side street, or to an alley and thus permit a curb higher than the lawns alongside, and in other instances utility requires the street to be filled to a considerable height above the adjacent property for short distances, but these are special cases.

Occasions also arise where the curb is very much lower than the lawns of residences along the street. In such instances the sidewalk is ordinarily lowered so that a slope of about ¼ in. per foot is obtained from the walk to the top of the curb. The lawn is then graded back so as to slope sharply to the walk, or a long sodded slope is constructed. In those cases where the

lawns must be 5 or more ft. above the sidewalks, retaining walls are often constructed at the property line of sufficient height to retain the lawns.

In a business district the top of the curb must be enough below the floor line of the buildings along the street to permit

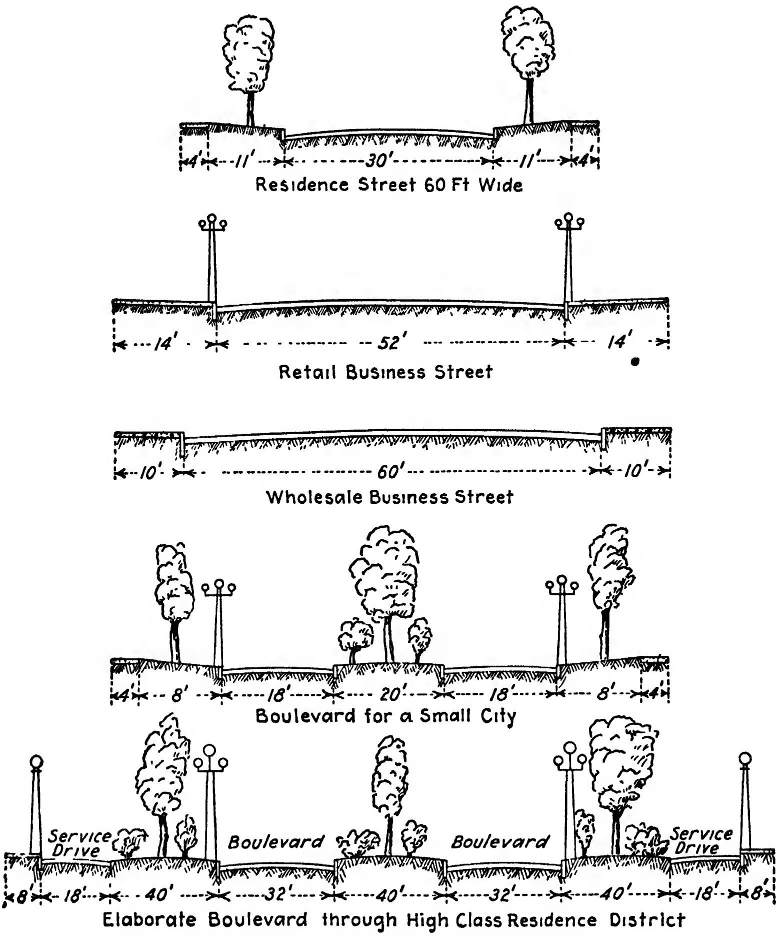


FIG 87.—Typical designs for streets.

constructing the walk with a slope toward the curb. Here again special cases may arise where the curb will be higher than the floor line, but these are unusual and must be considered as exceptions.

On business streets those buildings that have a floor line

considerably above the sidewalk must be provided with steps at the door to facilitate entrance This is exceedingly undesirable and if the condition exists throughout a block the sidewalk is more frequently placed at the floor line and steps are provided at the curb, an arrangement that seems to be much more satisfactory.

Since the sidewalks in a retail district are used by large numbers of pedestrians, the design of the street ought to include suitable facilities for pedestrians. Ramps can be provided instead of steps whenever room will permit, and every precaution be taken to insure convenience and safety of those who use the walks.

II The grades should be held to as low a per cent. as possible, but the necessity of connecting with intersecting streets and fitting to existing sidewalks and buildings will largely determine the grades.

It is comparatively easy to show that a great saving in energy will result from grade reduction on busy city streets, and doubtless instances constantly occur where large sums of money may wisely be expended to reduce grades. On the other hand, property lines have long been established and buildings have been erected in accordance with existing grades and lines, and any considerable change is likely to result in heavy damage to property. It is not uncommon to encounter grades as high as 8 per cent. on city streets, and sometimes grades as high as 15 per cent. exist and people endure them.

III. The grade line should be broken only at streets or at alleys. Often it is possible to provide a continuous grade for a full block or for a greater distance, and this should be done wherever feasible. If occasion demands, the grade may be changed at any street or alley intersection. The object of having the grade continuous for an entire block is one of appearance and of convenience to those using abutting property, and cannot be laid down as an inflexible rule.

IV. The type of surface to be used must be considered in determining the limiting grades or, if topographical conditions preclude grade adjustments, the streets must be paved with a material suitable to the grade. If it is necessary or desirable to use a certain type of pavement, such as creosoted wood block, then the grades must not exceed that which experience has shown to be the maximum permissible for that type.

The following table gives safe limits of grade for the various

types of surface where subjected to mixed traffic but as may be expected there is little uniformity in practice in this respect.

TABLE 40.—ORDINARY MAXIMUM GRADES FOR VARIOUS TYPES OF SURFACE

	Per cent
Wood block.	3
Asphalt block	6
Brick.	10
Sheet asphalt.	5
Bituminous macadam	8
Bituminous macadam without seal coat.	10
Concrete	8
Hillside brick.	12
Granite block open joint (sand or pitch filler)	12
Bitulithic, asphaltic concrete	7

Width of Pavement.—The width of the pavement is directly dependent upon the number of vehicles that will use it, and the width of the sidewalk upon the number of pedestrians. It is customary to allow a width of 8 ft. for each line of vehicles and a width of 2 ft. for each line of pedestrians. The minimum width for a residence street is usually 24 ft. and is based on the assump-

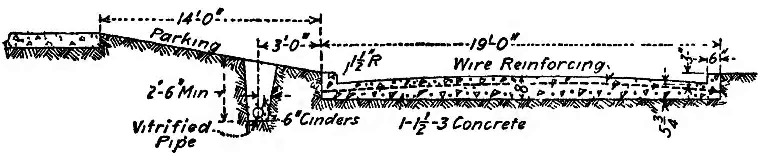


FIG. 88.—Pavement with a low curb.

tion that at times a vehicle may be standing at the curb on one side of the street and two others may pass at the same point. For convenience, then, the width must provide for three lines of traffic or 24 ft. Fig. 87 shows a cross-section typical of such a pavement. This will not always apply to little-used streets in small cities where the width may be reduced to 18 ft. Since a vehicle cannot readily turn around in that width, narrow pavements are constructed with a low curb so that a wheel can readily pass over it on occasion. Fig. 88 shows a cross-section typical of those used for this class of pavement.

If a residence street is closely built up and serves a large territory with many vehicles constantly passing, the width must be greater than 24 ft. It will be common to find vehicles standing at opposite curbs and there must be room between for two

vehicles to pass. The total width required is then 32 ft. In practice this is frequently reduced to 30 ft. Similarly a street may be encountered upon which, in addition to vehicles standing at opposite curbs, there may be fast or auto traffic and some horse-drawn traffic. It will frequently happen under these conditions that three vehicles will be passing at the point at which vehicles are standing at the curb, and a width of 40 ft. will be required. This is sufficient width for the most heavily traveled residence streets, except boulevards that carry a large amount of pleasure traffic.

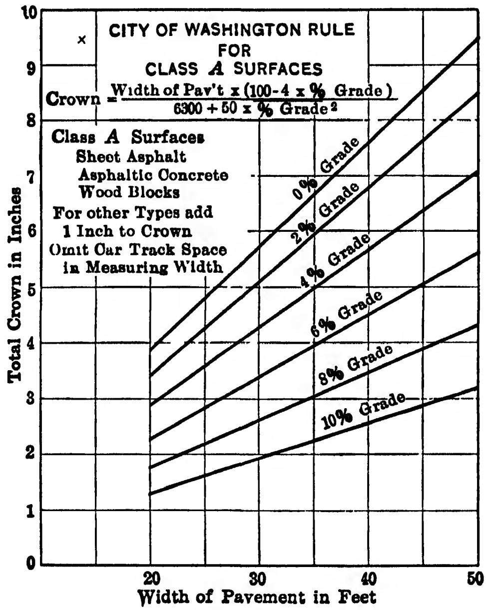


Fig. 89.

On boulevards it is not uncommon to have two distinct lines of traffic moving in each direction and the vehicles in each line constantly turning out to pass those in front. In addition, two lines of vehicles may be standing at the curbs, making in all eight lines of traffic to provide for and 64 ft. of paved width is the minimum that will be adequate.

If the street has a car line, 10 ft. of width should be added for a single track, and 16 ft. for a double track.

On business streets the same general principles are observed except that where the street is too narrow to provide both ample

carriage way and ample walkway, preference is given to the carriage way to some extent.

In a wholesale district the walkway is of secondary importance and the carriage way must be very wide. This is due to the necessity of trucks backing up to the curb to load and unload. This requires at least 16 ft. of width on each side or a total of 32 ft. for vehicles standing at each curb. If, in addition, provision is made for two lines of traffic and a double-track car line, a total width of 64 ft. is necessary. Often it is desirable to

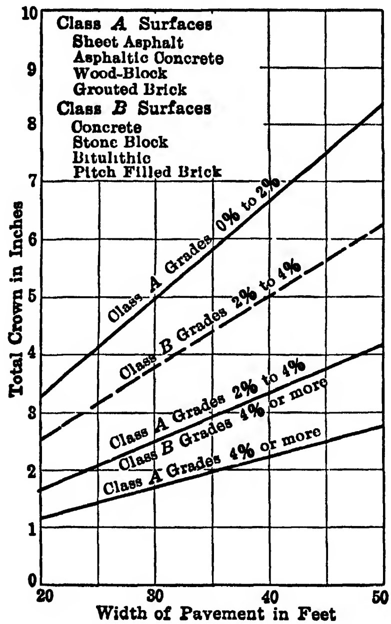


FIG. 90.

provide for four lines of moving vehicles or a total width of 80 ft.

In every instance the width of a pavement should be determined only after a careful traffic census has been taken and analyzed. To be too conservative as to the needs of the traffic is to insure congestion on the improved street and to restrict the movements of vehicles so as to seriously hamper the handling of commodities.

Cross-slope.—The cross-slope of a pavement is provided to cause the water to flow to the gutters. If the surface is rigid

and dense and exceedingly regular, a very slight cross-slope is sufficient. If the surface is somewhat elastic and apt to become slightly uneven, a greater cross-slope is required.

The slipperiness of any pavement is somewhat increased by an increase in the cross-slope; hence with those types of pavement that tend to become slippery, it is customary to use as slight a cross-slope as is consistent with drainage.

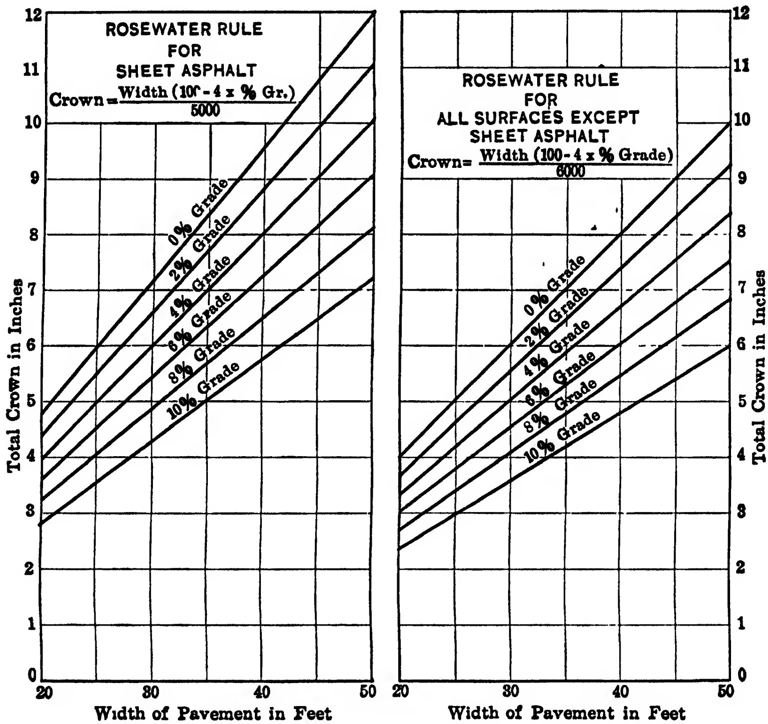


FIG. 91.

On hills the drainage is taken care of without regard to the cross-slope, and, consequently, in order to avoid an increase in slipperiness, only enough cross-slope should be used to insure that the water will work gradually to the curb.

Since the amount of water flowing on the pavement will increase toward the curbs, it is desirable to gradually increase the cross-slope as the curb is approached. This is accomplished by making the finished surface parabolic in form with the vertex at the crown line of the pavement.

The total crown to be used for various types of pavements may be determined from the diagrams shown in Figs. 89, 90, 91 and 92. These are well-known and frequently used rules, and, although they do not agree very closely, there are no data to indicate conclusively which is the best. Undoubtedly modifications of the amount of crown shown by the diagrams are frequently necessary to accommodate the pavement to local conditions, but the diagrams are satisfactory under average con-

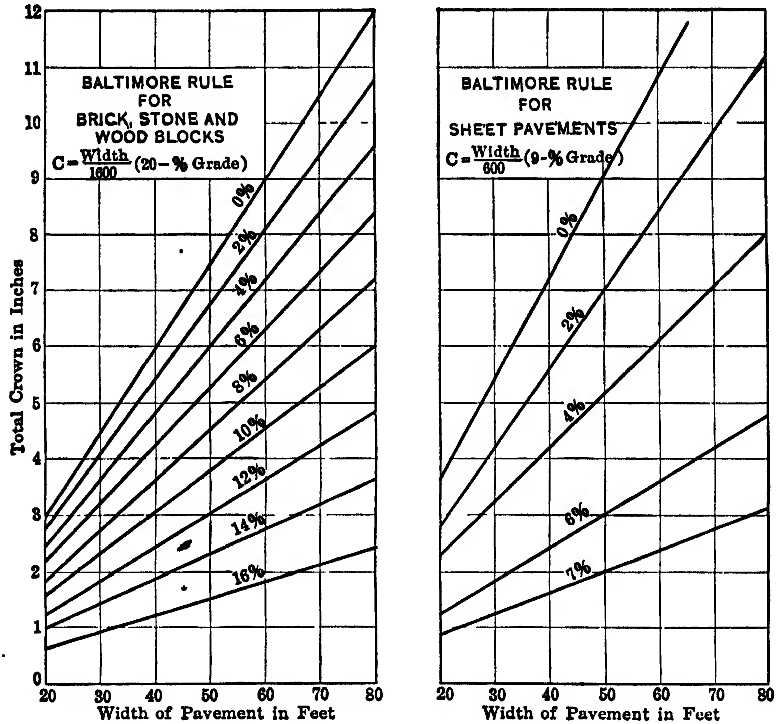


FIG. 92.

ditions. When the total crown has been decided upon, points on the cross-section can be readily determined from the parabolic formula. Usually if four points are determined that will suffice except on very wide streets. At one-fourth the distance from the center line to the curb the drop is one-sixteenth the total amount of crown; at one-half the distance from the center line to the curb the drop is one-fourth the total amount of crown. This is commonly referred to as the quarter point. At three-

fourths the distance from the center line to the curb the drop is nine-sixteenths the total crown.

If there are car lines on the street, the width between the outside rails should be deducted from the width between curbs in computing the crown, and the cross-section should be laid off from the outside rails instead of from the center line of the street.

Unsymmetrical Streets.—Many instances are encountered where the gutter lines of streets are not at the same elevation. This should be avoided so far as possible but sometimes it is the only design practicable; and if the property on opposite sides of the street differs more than 1 or 2 ft. in elevation, a symmetrical cross-section will appear to be unsymmetrical, an optical illusion that has been quite generally encountered by engineers. The unsymmetrical cross-section not only has a better appearance than the symmetrical but also simplifies the design at the intersection with other streets. When an unsymmetrical section cannot be avoided and the street does not have car tracks, the crown line or highest part of the pavement should be shifted to the high side of the street so that the cross-slope will be alike on both sides of the crown line. This is accomplished as follows:

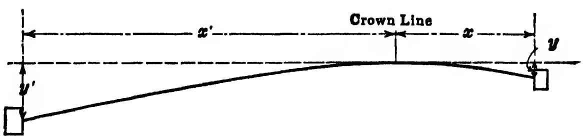
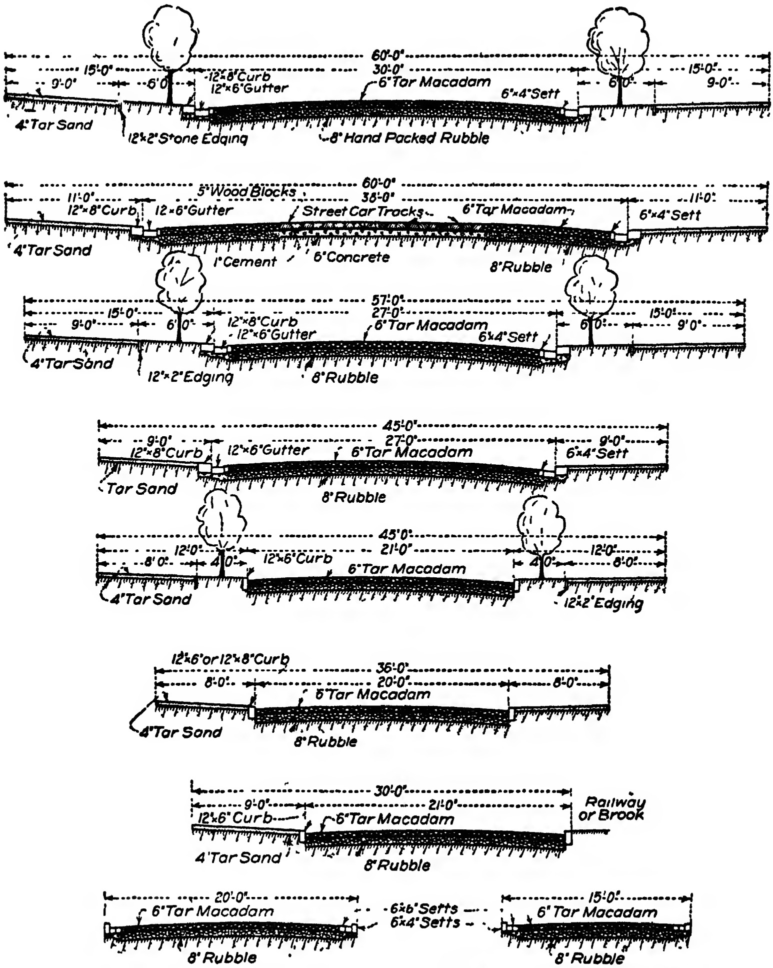


FIG. 93.

First determine the street that would have a crown equal to $y' - y$ (Fig. 93) which, for illustration, may be assumed to be 9½ in. This is the crown of a 50-ft. street, if sheet asphalt is used. See Fig. 89 (Washington, D. C., rule). Half of this is 25 ft. The difference between this width and that of the street shown in Fig. 93 is 35 ft. Determine the proper crown for a street 35 ft. wide which is 6¾ in. The crown line would then be 25 plus 17½ equals 42.5 ft. from the low curb (x', Fig. 93), and the total crown on the low side of the pavement would be 9½ plus 6¾ equals 16¼ in. (y', Fig. 93), while on the side next the high curb the crown would be 6¾ in. (y, Fig. 93).

It is apparent that 15¾ in. is not exactly the theoretical crown for a street of a half width of 42.5 ft. (85 ft. wide) since,

according to the formula used the crown would be 16¼ in. The exact width for which 15¾ in. is the proper crown can be computed and a second approximation can be made and thus arrive at very nearly the ideal crown for the portion of the pavement on



Courtesy Engineering-Contracting

FIG. 94.—English practice in street layouts.

the low side, but since all of the rules are empirical it is unnecessary to go to that refinement in general practice.

Car Tracks on Unsymmetrical Streets.—If a single car track is to be provided for on an unsymmetrical street, it should be placed at the crown line and not at the middle of the street. If the

street is too narrow to permit this, then the crown line must coincide with the rails and the slope in the high side of the pavement reduced to the lowest possible amount, so as to hold down the necessary slope on the low side of the pavement. If a double-track car line is to be provided for, each track should be placed with the outside rail at the elevation determined for that point on the cross-section by the preceding paragraph. This will necessitate sloping the pavement sharply between the tracks, but since that part of the street is little used by vehicles and the portion outside the tracks is, it is the best solution to a very unsatisfactory condition. At street intersections the tracks would be brought to the elevation of the intersecting pavement.

Here again the lack of room or other conditions may force the tracks to the middle of the street and necessitate a steep slope on the low side of the pavement. This is dangerous when the pavement is slippery and unsatisfactory at any time.

Intersections.—In the design of intersections three factors must be considered; the safety of traffic, the comfort and con-

FIG. 95.—Showing false curb and cover plate over the gutter at the cross-walk.

venience of pedestrians, and the proper disposition of storm water.

Since vehicles will be constantly turning the corners, the slope of the pavement ought not to be too great and should preferably be in the direction that will favor traffic. In the ideal case the pavement will slope upward from each of the four curb corners to the crown line. Every possible effort should be made to establish the grades so as to bring about that con-

dition, but when it is impossible the departure should be only so much as demanded by the conditions.

For the comfort and convenience of pedestrians the sidewalks are commonly raised only a short step above the gutter, and are constructed with a moderate slope upward from the curb. Innumerable special conditions arise to modify the ideal plan, but the departure from the ideal should be no greater than necessary. The maximum allowable cross-slope for a sidewalk is ¾ in. per foot, but a much lower slope is decidedly preferable. The ideal slope is about ¼ in. per foot.

Storm water should be disposed of by means of manholes and catch-basin inlets so constructed that they do not inconvenience traffic and without danger of flooding the intersection.

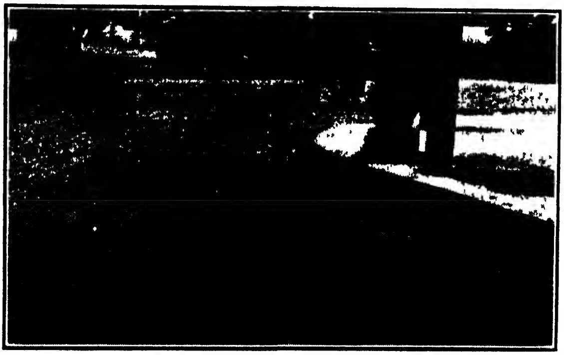


Fig. 96.— Showing intersection pavement warped up to the top of the curb at the cross-walk.

In residence districts the plan shown in Fig. 95 is commonly employed. The pavement at the crosswalk is warped up to the elevation of the curb, a false curb and cover provided at each gutter and one catch-basin constructed at each corner. The sidewalk is thus made continuous across the pavement and the water flows between the false curb and the true curb, but under the cover plate. The width of the channel between the curb and the false curb is usually 6 in., but 8 or 10 in. is sometimes necessary. This type of intersection has the disadvantage of being uncomfortable for vehicles turning the corner, particularly if they "cut in." But on residence streets where traffic is light, it is a satisfactory type of intersection and takes care of the drainage without inconvenience to pedestrians. A modification of this type of intersection is shown in Fig. 96. The pavement is

warped up to the top of the curb at the crosswalk and thus the walk is continuous across the street The catch-basin for the street water is placed some distance from the crossing and the gutter is sloped away from the crossing. The water from the intersection is taken care of by four catch-basins placed at the four curb corners, each taking the water from one-fourth of the intersection area.

Not infrequently the intersection is constructed without provision for pedestrians to cross the gutters without wading when storm water is flowing, but this is poor practice, especially in residence districts.

The two types of intersection mentioned above are entirely unsuited to business streets or other streets where traffic is heavy,

Fig. 97.—Showing special gutter design for streets where automobiles regularly stand at the curb.

because of the inconvenience to traffic caused by the warped-up pavement at the crosswalk.

For business streets two general methods of caring for drainage are in common use. These are designed with many variations as to detail, but the essential points are alike. At the walk corners the pavement is warped up to the level of the curb entirely around the corner, and drainage is provided as indicated by the arrows in the figure. A variation in this plan is to provide catch-basins as shown but to continue the gutter around the corner so that pedestrians must step up or down at the curb.

The other general plan is to provide a single water inlet at each curb corner with the gutter continuous around the corner. When

any considerable amount of water is flowing, pedestrians must wade across and this is, of course, undesirable.

Central Gutter Pavements.—From time to time engineers have advocated the construction of pavements with the gutter at the middle. This is the common practice for alley pavements and, in a few instances, street pavements have been so constructed. The practice has never become general because some of the objections such as numbers 1, 2 and 3 in the following, apply to fundamental characteristics and probably cannot be entirely

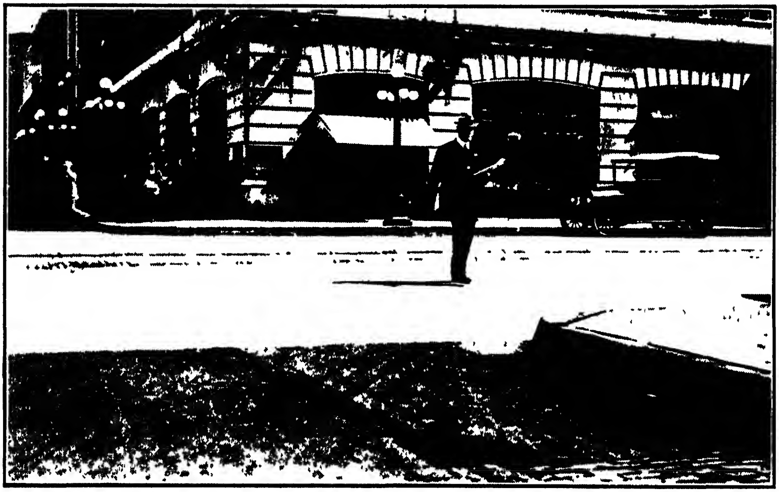


FIG. 98.—Showing conventional intersection design for a business street.

overcome. The following categorical statement is believed to fairly represent present opinion in the matter.

ADVANTAGE OF A CENTRAL GUTTER[1]

Some of the principal advantages of such a pavement are as follows:

1. The capacity of the pavement to carry storm water is many times that of the pavement constructed in the old way.
2. It will keep the dirt and filth in the center of the street where it was made and where it can be easily cleaned or washed away.
3. With this construction it will be easier and more convenient

[1] W. G. Kirchoffer, in *The Municipality* for January, 1916.

to establish street grades to conform to existing conditions than it is with the present method of street construction.

4. It will be more economical in the cost of catch-basins and sewers, as one or possibly two catch-basins will take the place of four or more.

5. No need of deep gutters with costly covers for sidewalks, which are an obstruction to the street.

6. Lower curbs or none at all in the residence sections, except such as might be formed of sod.

7. Greater convenience in driving up to the curb. No mess of water, filth, paper, cigar stubs, etc., to alight into from a carriage or auto.

8. More sanitary because storm water, or water from street washing, would be more concentrated and therefore wash the street cleaner.

9. The appearance of the street will be improved from the esthetic point of view.

10. Less crown (or anti-crown) in this case will be needed.

11. Street will be more easily cleaned, as the debris will be concentrated in one windrow in place of two as now.

12. This form of street pavement will tend to divide traffic to right and left side of the street.

13. Great advantage on boulevarded streets where four gutters are now necessary.

14. Where concrete is used as a paving material the tendency to crack along the center line will be reduced because the expansion of the pavement, due to temperature changes, will put compression stresses in the pavement at the center line instead of tension stresses as is now the case when the street is crowned at the center.

DISADVANTAGES OF PAVEMENT

Some of the disadvantages to such a form of street are:

1. On a narrow street with car tracks, the gutter would be between the rails which would cause débris to accumulate in the wheel grooves. This objection could be eliminated on a wide street by making a low point each side of the car tracks.

2. During heavy storms the stream of water in the center of the street might be too deep to walk through.

3. Where the grade is slight and where there is freezing and

thawing weather, water may collect in pools 4 to 6 ft. wide, freeze and make traffic in the center of the street difficult.

4. If pavement is made thick at the curb and thin at the center, fear has been expressed that the pavement would crack along the center line.

5. Fear has been expressed that rapidly moving vehicles at street intersections would tend to skid toward the center of the pavement instead of toward the curb, as would be the case of a crowned street. This contention would be true in case of vehicles turning around a corner to the right, but if the vehicle was turning to the left the new form of surface would tend to keep the vehicle in the street and right side up, while with the crowned surface, as at present, the vehicle has a tendency to skid down the crown toward the curb and possibly overturn.

The Design of Street Intersections.—One of the most troublesome problems encountered in street design is the establishment of grades at intersections. So many and diverse are the conditions encountered that no simple rules can be laid down covering all cases. Moreover, practice has not been anywhere nearly standardized, nor can it be. The design of intersections is therefore a matter for special study every time it presents itself. A few fairly well defined principles may be laid down that will serve as a guide in working out most of the cases that occur.

Streets with Grades less than 2 per cent.—(*a*) The center-line grade is carried without a break across the intersection and the curbs on opposite sides of the street are not at the same elevation. The difference in elevation on a 40-ft. street with a 2 per cent. grade will be 0.8 ft. and this can readily be taken care of by either varying the height of the curb so as to keep the gutters at nearly the same elevation, or by using an unsymmetrical cross-section for the street, or by both means. It may be desirable to keep the curbs and the pavement cross-section symmetrical on the more important of two intersecting streets, and have a break in the grade line of the other at the curb line of the first. This is frequently done where one street is a main thoroughfare and the other a cross street.

As a general rule difficulty is experienced in securing a safe and properly drained intersection if the difference in elevation of the opposite curbs is much greater than 1 ft., *i.e.*, on a 50-

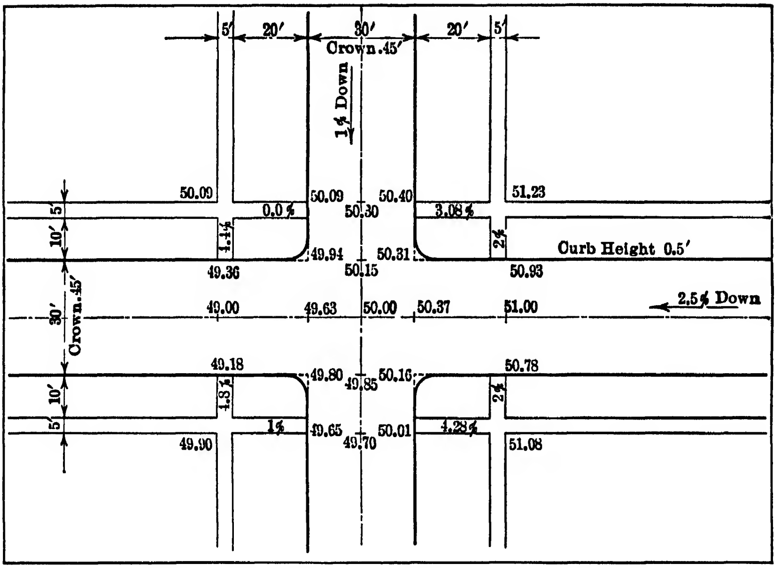


FIG. 99.—Design of intersection for residence street with light grades.

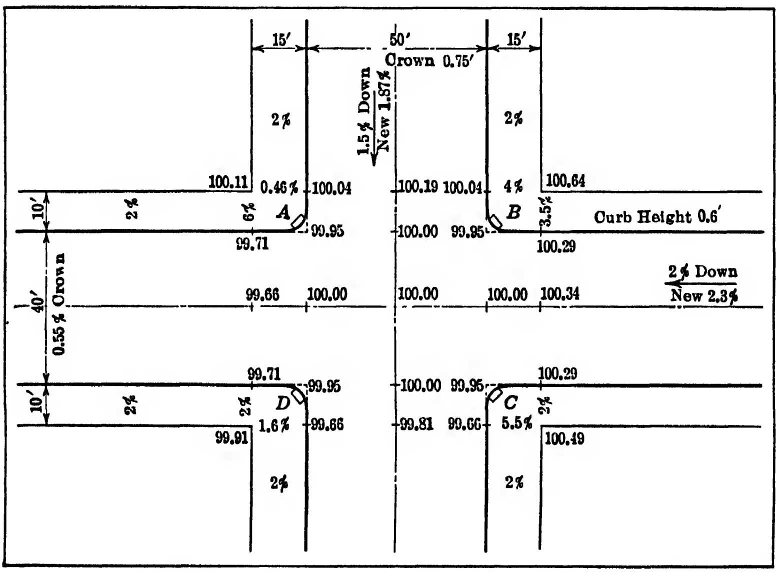


FIG. 100.—Design of intersection for grades less than 3 per cent.

ft. pavement when the grade of the intersecting street is 2 per cent. When such is the case, method (*b*) may be used. Fig. 99 shows the design of an intersection for a residence street with slight grades.

(*b*) The other method of designing intersections for streets of light grades is to make the elevations of the four curb corners the same. The grade lines of each street will then break at the curb lines of the intersection. This design is generally easily carried out on residence streets, but may be difficult in a business district on account of the established building-line elevations. From the standpoint of securing an intersection that is safe for vehicles, it is to be commended. It has the disadvantage of putting the curb line somewhat below the level of the lots on the uphill side of the street, but this is a secondary consideration. Fig. 100 shows the design of an intersection for a business street with slight grades.

Streets with Grades Over 2 Per Cent.—If streets are on grades greater than 2 per cent. and especially if they reach 5 per cent. or more, it is frequently impossible to carry the grades continuously across intersections because of the difference in height of curb that would result, although it should be done if possible, The grade cannot always be broken at the curb line because of the difficulty of securing reasonable grades to the sidewalks, especially on business streets. On residence streets it is sometimes possible to adjust the grades of walks if the street grades do not exceed about 4 per cent., and make the break in street grade at the curb line of the intersecting street. When that is possible it is the best solution of the problem as it usually increases the grades on the remainder of the block less than any other method of treatment. Figs. 101 and 102 show designs of intersections for grades in excess of 2 per cent.

For business streets satisfactory grades at the intersection are secured by flattening the street grade across the intersection, making the break in the grade line at the property line of the intersecting street. It will easily be seen that this increases the grade along the remainder of the block.

This emphasizes the desirability of flattening the grade only so much as is necessary to secure a satisfactory intersection This can only be determined by repeated trial for any given intersection. On account of the variation of width of paving and sidewalk, no uniformity exists in the procedure, but whatever

modification is made looks to one end, viz., to secure an intersection with reasonable slope and sidewalks that fit to the curb grade without undue cross-slope. This cross-slope may be as great as 6 per cent. and in exceptional cases 10 per cent., but for ordinary cases should be held as low as 2 per cent.

For the intersection of streets crossing at excessive grades or for streets intersecting at acute angles, the problem becomes very complicated and the procedure outlined by Mr. Vernon S. Moon in a paper read before the Municipal Engineers of the City of New York has been widely quoted and commended. It is given as one of the examples of good practice at the end of this chapter.

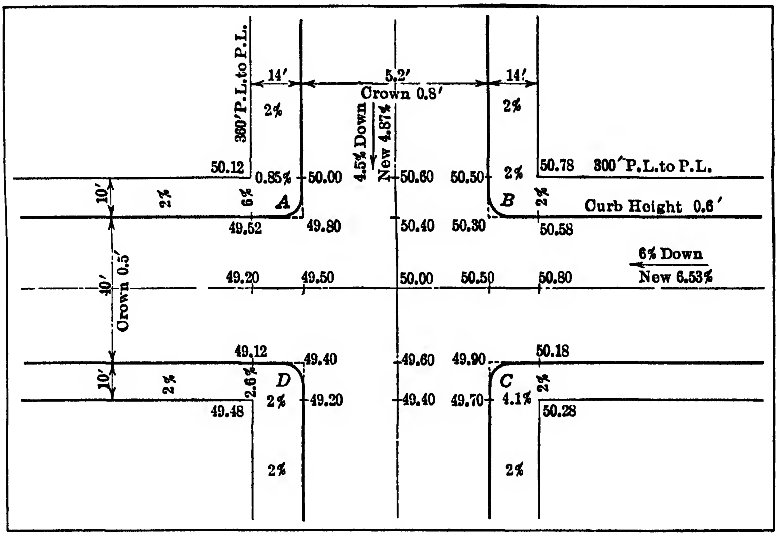


FIG. 101.—Design of intersection with steep grades

Curbs.—Curbs are used at the edge of the pavement except in those cases where the street is in the outskirts of the city and in reality serves the purpose of a country road. The curb defines the edge of the pavement and thus adds somewhat to the appearance of the street; it retains the soil and sod on the parking so that it will not wash onto the pavement; it serves to confine traffic to the paved area thus protecting the grass plots or sidewalks from the encroachment of traffic and it serves as one side of the drainage channel directing the water into the proper outlets. Thus the curb serves a utilitarian as well as an

ornamental purpose. Both appearance and utility must be considered in the design and construction.

Height of Curbs.—The height of curb is dependent partly upon securing good appearance and partly upon having ample height to prevent traffic encroaching on the grass plots or sidewalks. In special cases it may also depend upon the amount of storm water carried in the gutter. A uniform height of curb is desirable because of the appearance and in residence districts this height is usually either 6 or 8 in. In business districts the height of the curb is usually either 6, 8 or 10 in., but the tendency is to have it somewhat higher on the average than in residence

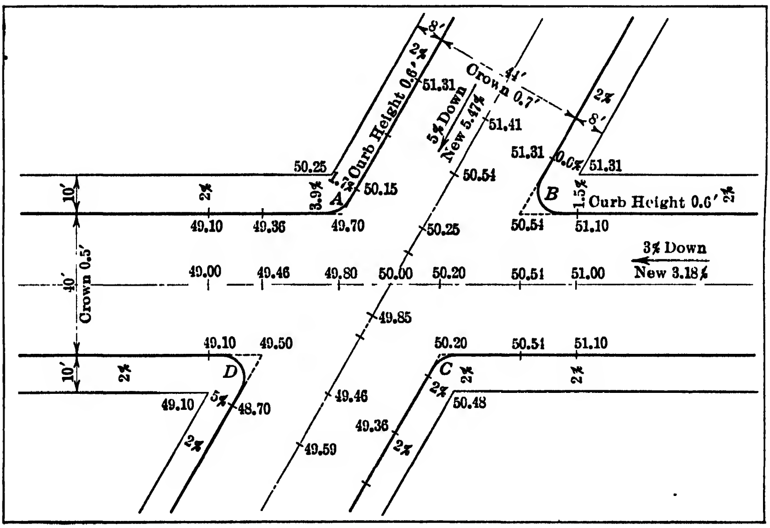


Fig. 102.—Design of intersection for diagonal streets.

districts. At corners the curb should never be less than 6 in. high so as to prevent vehicles cutting in on the grass plots or walks in turning the corner.

In cities where the street grades are very light, it is frequently necessary to secure drainage by sloping the gutter independent of the grade of the crown line of the pavement, which results in the curb height varying along the block. This does not look as well as if it were of the same height, but is not otherwise objectionable.

In hilly cities many special conditions arise requiring a variation in the height of the curb from point to point along the

street or on opposite sides at the same point. These conditions are unavoidable and are objectionable only on account of the appearance.

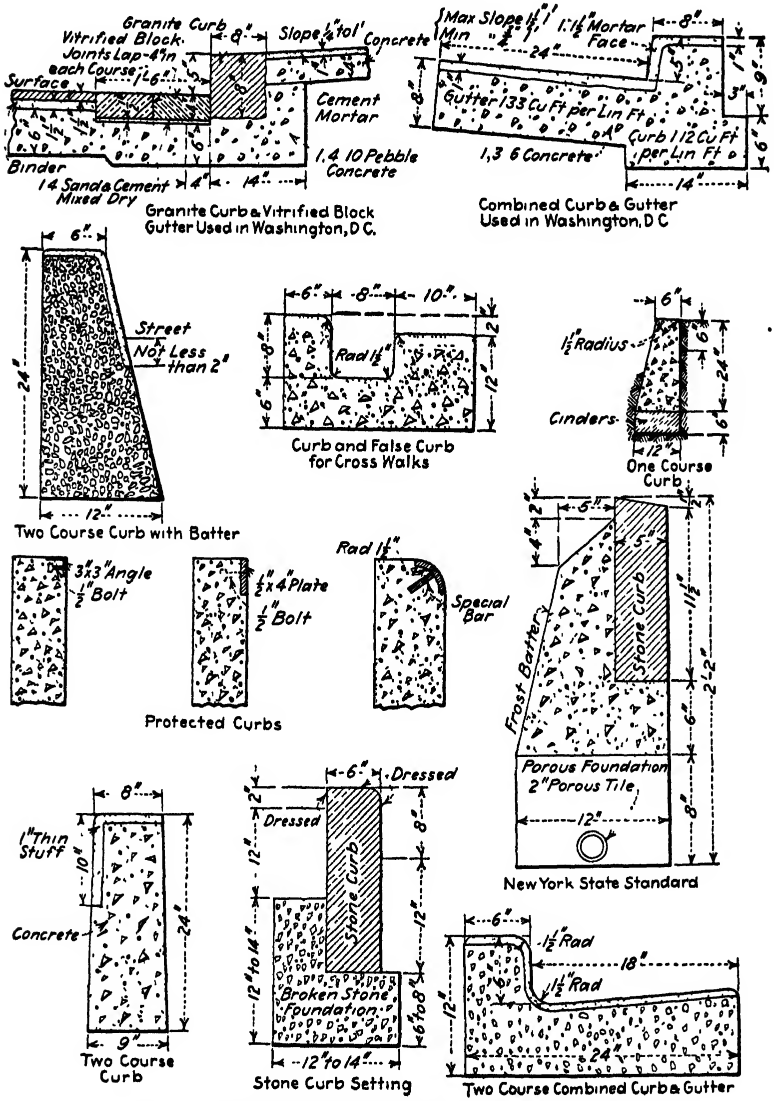


FIG. 103.—Designs of curbs and combined curb and gutter.

Stone Curbs.—Sandstone, granite and limestone are used for curbs, the latter less commonly than the other kinds. The size

of the blocks used is variable but for residence streets and for ordinary business streets it is usually 5 in. thick and from 4 to 8 ft. long. The depth will depend upon the thickness of the pavement and the amount of exposed face desired.

For streets where heavy trucks are likely to back in against the curb, granite should be used if it is advisable and the thickness should be at least 6 in. and 8 in. is better.

The curbstones should extend to the bottom of the pavement base and the total height of the stones will, therefore, depend upon the kind of pavement and is usually between 16 and 20 in.

Radius Curbs.—The curb is curved at the corners where streets or alleys intersect. The radius at alley corners may be 3 or 4 ft. and at street corners 6 to 9 ft. on business streets, and 6 to 12 ft. on residence streets. The longer the radius the easier for traffic to round the corner, but this cuts in on sidewalk space on business streets and that limits the possible radius to about 9 ft. Radius stone are more expensive than straight curbs, and the longer the radius, of course, the more expensive. For that reason the radius is held as low as consistent with reasonable convenience at the corners. The curved portion of the curb is formed with stone that have one face dressed to the prescribed radius, while the back may be either dressed to a corresponding radius or may be a chord. Usually the corner is formed with two radius stones, but on the curves of a radius exceeding 6 ft., more than two stones are commonly employed. The ends of radius stone are dressed to a radial line so that the joints will be of uniform width.

Concrete Curbs.—Portland-cement concrete curbs are quite extensively used, especially where suitable stone curbing is expensive. The concrete curb is usually made 6 in. thick and deep enough to reach to the bottom of the pavement base. The aggregates used are sand and broken stone passing a ¾-in. ring and retained on a ¼-in. ring. Where it may be secured, granite or some equally hard stone is desirable, but a good quality of limestone may be used satisfactorily. Graded and bank-run gravel are also widely used. The mixtures employed are 1 part cement, 2 parts sand, and 3 parts stone, or 1 part cement, 2½ parts sand and 4 parts stone, the former being preferable. The general principles already discussed as applying to the selection and testing of concrete materials apply to curb work as well as to any other kind of concrete construction.

The exposed face of the curb and the top is finished with a wood

float to give a rough or granular appearance not unlike that of sandstone. This is accomplished by tamping the concrete in place and allowing it to set sufficiently to permit the removal of the forms. The forms are removed as soon as possible and the curb is scoured with a wood float and water until the desired surface is obtained. This cannot be carried out successfully if the finishing is delayed too long.

In other instances the concrete is placed between metal forms or smooth plank forms, and the top is finished with a steel float. The face receives no special finish, but if the forms are smooth the face will be smooth and not unsightly.

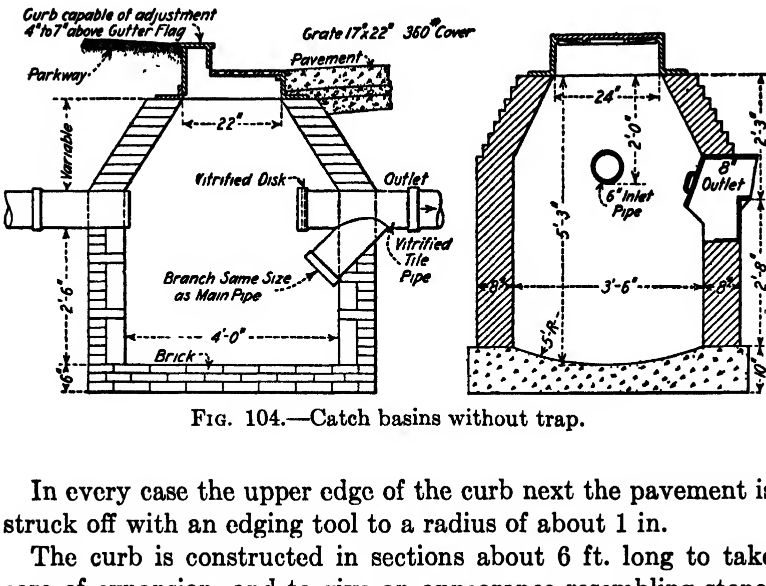


FIG. 104.—Catch basins without trap.

In every case the upper edge of the curb next the pavement is struck off with an edging tool to a radius of about 1 in.

The curb is constructed in sections about 6 ft. long to take care of expansion, and to give an appearance resembling stone. The sections are separated from each other during construction by means of a metal platen ⅛ in. thick which is set in the forms and serves as a partition to separate the sections. Cutting the sections with a trowel does not answer the purpose. After the concrete sets the platen is removed, leaving a joint between the sections.

Much difficulty is experienced at curb corners unless adequate provision is made for expansion. It is good practice to provide an expansion joint 1 in. wide between the last straight section of curb and the first section of radius curb at the corner. It is

usually unnecessary to fill this joint, but if a filler is used it should be some kind of elastic felt.

Like the stone curb, the concrete curb should be placed on some substantial foundation such as hard-tamped clay, stone, gravel or cinders. Fig. 103 shows settings used for curbs.

Armored Curb.—The curved portion of the curb at corners and sections where trucks are likely to back in against it are protected by a metal plate which is built into the curb. Fig. 103 shows three types of protection commonly employed, but many others are used.

For severe service the concrete curb should be made 8 in. thick and should have a heavy protection plate.

With concrete pavements the curb is often made integral with the pavement, as discussed elsewhere.

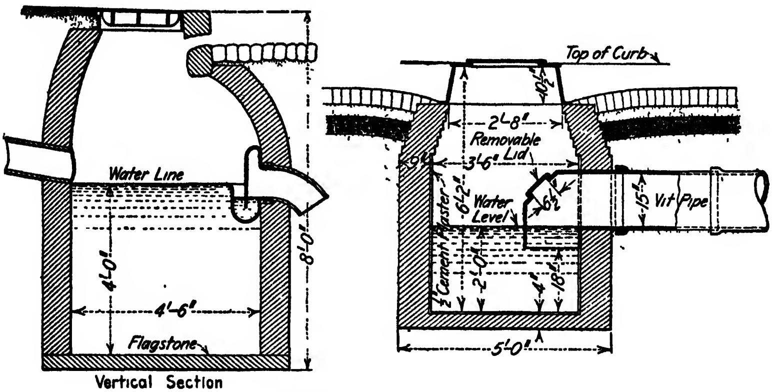


FIG. 105.—Catch basins with trap.

Curbs on Country Brick Roads.—The curb on a brick country road is made integral with the base and with the top level with the surface of the pavement (see Fig. 50). It is usually made of a better mixture of concrete than the base because it will be subjected to some wheel wear and is constructed after the base has been completed but before it has had time to set.

Concrete Combined Curb and Gutter.—This type of curb is used on residence streets where a smooth gutter is desired or where the appearance of such a curb is deemed superior to that of the straight curb. It is commonly constructed of a rather lean base and with a rich mortar coat of about ½ in. thickness, for the surface. The size varies considerably and Fig. 103 shows a few of the commonly used designs for this type of curb. Formerly

it was deemed impractical to build this curb of varying height, but methods of construction have been perfected that make it possible to do so, and maintain a constant width of gutter slab.

The base is usually made of 1-2½-5 mixture and the surface a 1 to 2 mortar. The forms are set and the concrete for the base which is mixed with but little water is tamped in place and struck off. The front form board for the curb is then removed and the mortar coat is applied and struck off by means of a templet drawn along the side form boards. If the curb is not of uniform

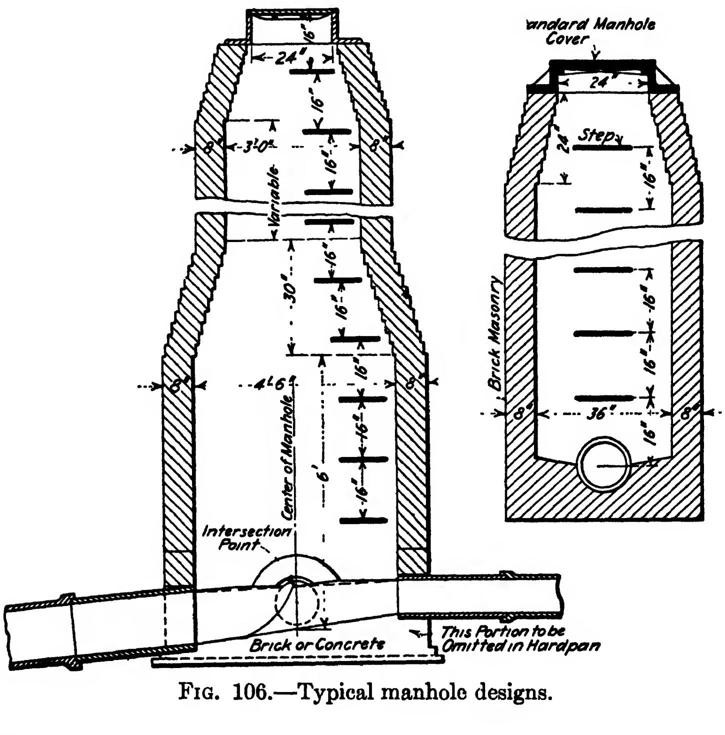


FIG. 106.—Typical manhole designs.

height the templet for the top of the curb is omitted, and that is finished by means of the trowel or steel float. Care must be used in the construction to insure a neat and workmanlike finish, and the mortar coat must be applied before the base has taken a set. If dust from the street settles on the base before the top is applied, or if the base has taken a set, it will prevent the mortar coat from adhering and later it will scale off.

As with straight curbs the combined concrete curb and gutter is made in sections separated by metal platens set in the forms

and same provisions for expansion are necessary as are employed with straight curbs. The combined curb and gutter must be placed on a substantial foundation of well-tamped gravel or cinders. The grade and alignment must be carefully maintained for the sake of appearance, and to insure good drainage.

In recent years this type of curb has been built of one course of 1-2-4 concrete in the manner already described for the straight curb. This is particularly desirable if it appears that traffic will get out on the gutter slab to any extent.

The concrete combined curb and gutter should not be used for business streets because the constant use of the gutter slab as a pavement will wear the slab so that it will become rough and uneven. It is also quite likely to wear into a groove at the line where the pavement proper joins the gutter slab.

Special Gutter Designs.—With most types of sheet pavements it is desirable to provide a gutter of some inelastic material for some traffic conditions. If vehicles stand at the curb on a sheet pavement, the wheels will form depressions that will hold water and thus interfere with drainage. It is good practice to provide a gutter slab about 18 in. wide made of concrete, vitrified brick or creosoted wood blocks. Either the concrete or stone curb may be used.

Where the streets are on grades exceeding 3 per cent. some difficulty is experienced in starting the load on wood-block and sheet pavements because of the poor footing afforded for horses. Horse-drawn trucks that stop at the curb to deliver goods are thus inconvenienced. If vehicles stand continually along the curb it is desirable to provide an inelastic slab in this area. The gutter slab for such locations is sometimes made about 6 ft. wide, constructed of vitrified brick or stone blocks. The remainder of the pavement may be creosoted wood blocks or a sheet surface. This type of gutter slab is undesirable for sheet surfaces on heavy traffic streets because of the tendency for a rut to form at the edge of the slab. Fig. 97 shows a special design of curb and gutter.

Catch-basins.—Storm water from pavements is ordinarily disposed of by means of storm-water sewers or by means of sewers carrying both storm water and sewage, but the former is the more common method.

The street water will carry miscellaneous rubbish, manure, and often considerable quantities of soil. If this material gets into

the sewer it is likely to become lodged on some obstruction and finally the accumulation will clog the sewer. For that reason the street water is first taken into a catch-basin and from the catch-basin the water, freed of most of the detritus, flows into the sewer. The catch-basin is so designed that it can be cleaned out as occasion demands.

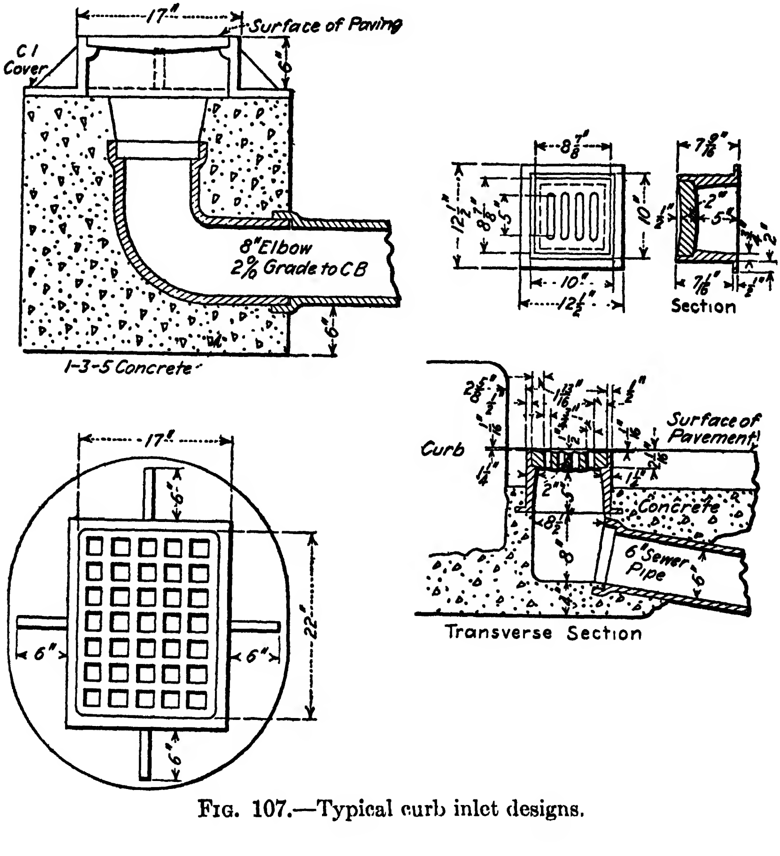


Fig. 107.—Typical curb inlet designs.

Catch-basins may be constructed beneath the gutter, entirely under the paved area or they may be constructed just back of the curb in the sidewalk area or in the sodded space of residence streets. The catch-basins are of a wide diversity of design, a few of which are shown in Fig. 104. If the storm water is taken into a combination sewer, it is necessary to provide a water seal or trap so that odors will not reach the street from the sewer. Fig. 105 shows the design of catch-basins of this type.

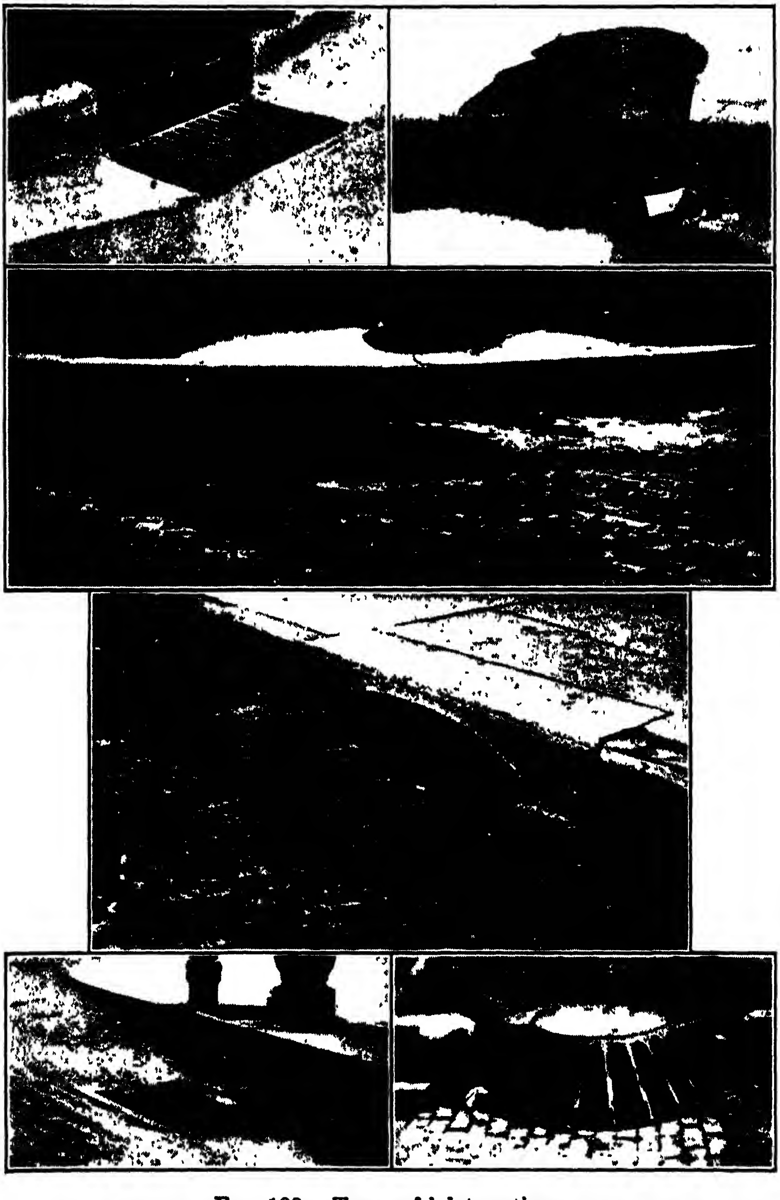


FIG. 108.—Types of inlet castings.

Manholes.—At the junction of the pipe from a catch-basin and the sewer, the connection is made by means of a manhole. The drains from several catch-basins often lead to the manhole through which the sewer is carried. Fig. 106 shows a few types of manholes.

Curb Inlets.—Sometimes street water is taken directly to the sewer instead of through an intervening catch-basin, and when such is the case the curb inlet is employed instead of the catch-basin. The curb inlet differs from the catch-basin only in that it has no receptacle for collecting the street refuse carried by the water. Several types of curb inlets are shown in Fig. 107.

Catch-basins and Curb-inlet Covers.—The perforated covers through which the water flows into the catch-basin or inlet are of great variety, and the particular type employed in any case will depend, to some extent upon local conditions and to a greater extent upon cost. A simple perforated or slotted cover is to be avoided if any considerable quantity of paper, leaves or other similar material is likely to be washed to the catch-basin, as the opening will clog readily. The type that provides a slotted grating for the gutter and a false curb with a large opening is to be preferred in this case. Fig. 108 shows a few of the many types of castings that are in use.

CAR TRACK PAVING

Types of Pavement for Car Tracks.—Whether the car-track paving shall be of the same material as that used on the remainder of the street depends upon several conditions. Any street that carries a large amount of heavy truck traffic must have a very durable type of pavement and the car-track paving may be of the same type as the remainder of the street. Streets that are paved with stone blocks, wood blocks or vitrified brick generally have car tracks paved with the same material.

If the traffic is mixed and not as heavy as indicated in the preceding paragraph the car track paving may be of some more durable material than is used for the remainder of the street. It will readily be seen that in turning on to the car track, or in crossing it, there is a tendency for the steel-tired wheels to slide along the rail for a distance, thus bringing severe wear on the paving next the rail. At crossings where the tracks curve around corners or the trackwork is otherwise complicated the paving is

likely to be cut up into small areas that receive severe service. In such cases it is good practice to provide a very durable car-track pavement. Thus we often find that streets that are paved with sheet pavements (sheet asphalt, asphaltic concrete, bitulithic, etc.) have car tracks paved either with wood blocks, granite blocks, or vitrified brick.

Even for moderate-traffic streets paved with sheet surfaces it is common to use a "toothing" along each rail. This consists

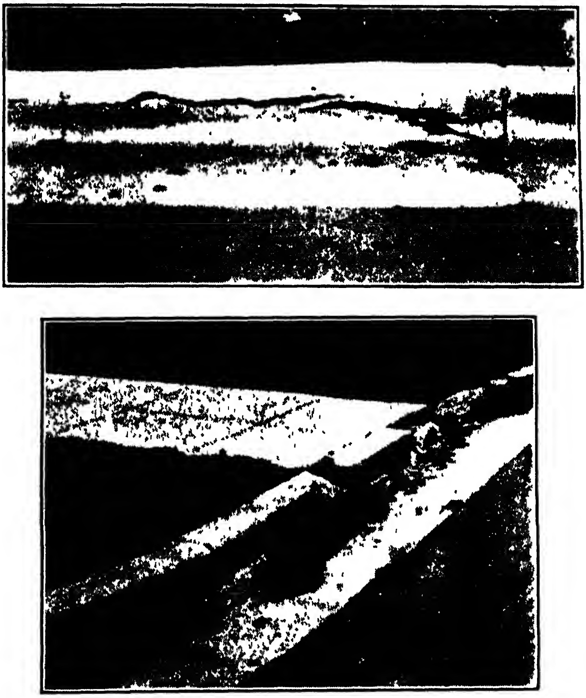


FIG. 109.—Illustrating need of expansion joints in curbs and walks.

of one or two rows of wood blocks or vitrified brick laid along the rail with the long dimension parallel to the center line of the track.

Types of Car-track Rails.—The type of the rail is an important factor in the life of the car-track paving. Three types or modifications of them are employed. If a car track is not adequately supported the continual vertical motion of the rail as the cars pass will gradually loosen the paving blocks adjacent to the rail. Once loosened, water enters and softens the supporting soil

under the ballast and hastens the deterioration of both track and pavement.

The effect of any movement of the track is increased if the paving blocks extend under the head of the rail.

T-rails.—The T-rail is of the form that is used for steam roads except that the rail is higher so as to permit the pavement being placed above the ties and to afford a more rigid support for cars. Where the rail is of this type a special-shaped paving block is

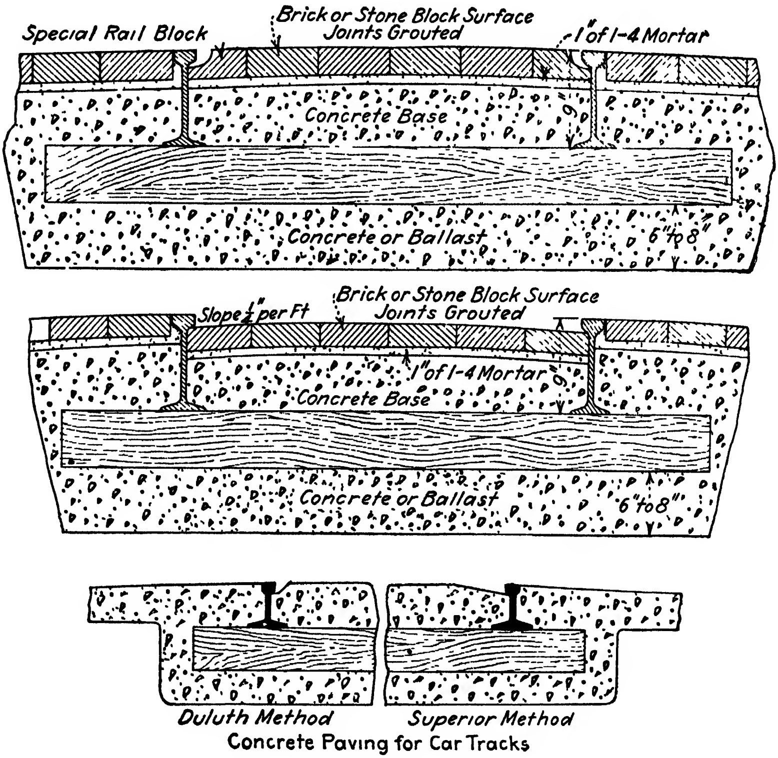


FIG. 110 —Paving along T rails.

often employed to form a groove for the car-wheel flanges. This is not a satisfactory type of car-track paving for streets of heavy vehicular traffic because drivers will permit the wheels of vehicles to travel in the groove next the rail and the concentration of traffic soon wears out the paving. Fig. 110 shows the arrangement of the paving along rails of this kind. The T-rail is most economical for the street car company.

Grooved Rails.—The shape of this rail is best shown by Fig. 111 which also shows the arrangement of the paving along tracks of this kind. Since the top of the rail is even with the pavement surface there is no tendency to guide the wheels of vehicles along the track.

Lipped Rails.—This rail is similar to the grooved rail as will be seen by reference to Fig. 112.

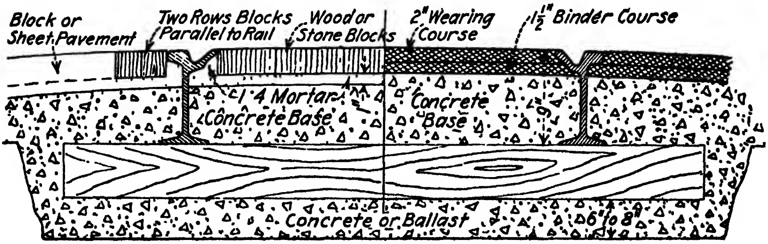


FIG. 111.—Paving along grooved rails.

Track Construction.—Regardless of the type of rail used, increasing attention is being paid to the track construction and especially to the foundation construction. The thickness of the ballast under the ties varies with soil conditions but is rarely less than 6 in. and often is more than 1 ft. The difficulties encountered with car-track paving are generally due to insufficient

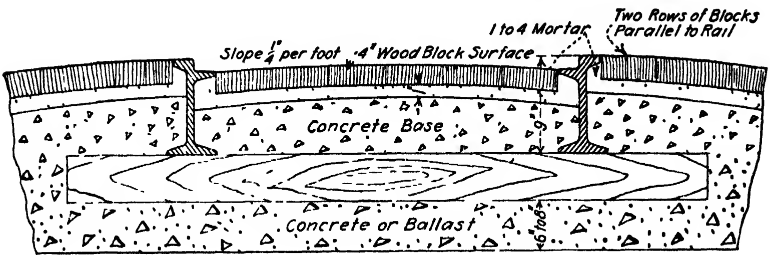


FIG. 112.—Paving along side-bearing rails.

stability of the track. Figs. 110, 111, 112 show the recommended practice for car-track construction on paved streets and represent the minimum requirements permissible.

Pavement Foundations.—The design of the foundation is one of the neglected factors in pavement design, probably because foundation failures are not always immediately apparent or are readily explained by "unforseen contingencies." It is apparent

that the foundation is the vital part of the pavement and should be carefully designed. The function of the pavement is to transmit the load from the wearing surface to the earth subgrade and in so doing to distribute the load over sufficient area that the subgrade will not be distorted by the pressure. The necessary thickness depends upon the nature of the earth foundation, the bearing power of the soil, the weight of the loads that the pavement will carry and the rigidity of the wearing surface.

For any known soil condition the foundation thickness needed for a sheet surface is greater than for a block-pavement surface carrying the same traffic. Likewise the macadam or gravel foundation for a given surface must needs be thicker than a Portland-cement concrete foundation for the same pavement. Soils of low-bearing power require greater thickness than stable soils.

The proper thickness should be determined only after an examination of the soil that will form the subgrade and the special considerations of foundation thickness has been discussed for each type of surface in the preceding chapters. The following table of average thickness of foundation for good soil conditions will be of interest for comparison.

TABLE 41 —COMPARISON OF THICKNESS OF PAVEMENT FOUNDATIONS

Type of surface	Thickness of foundation for residence streets		Thickness of foundation for business streets	
	Gravel or macadam, in	Concrete, in	Gravel or macadam, in	Concrete, in
Granite blocks.			8 to 10	6 to 8
Wood blocks				6 to 8
Brick (grouted).	6	4	6 to 8	5 to 6
Bitulithic	8	5		6
Sheet asphalt.		5		6
Asphalt blocks.	6	5	8	6

EXAMPLE OF GOOD PRACTICE[1]

1. Definition of Platforms.—The center-line intersection shall be deemed to be the point of intersection of the center lines, except for cases where the center lines do not meet at a common point

[1] Mr. Vernon S. Moon in the proceedings of the Municipal Engineers of the City of New York, 1911.

when it shall be the area included within the center lines at their intersection.

The curb-line platform shall be deemed to comprise the area included within the lines connecting the points on intersection of the curb tangents, or in the case of a street terminating at another street it shall comprise the area within the prolongations of the curb lines across the intersection and a line joining the curb tangents.

The building-line platform for rectangular intersections shall be deemed to include the area bounded by the prolongations of the building lines of both streets across the intersection so as to comprise the greatest platform area. In the case of other than right-angled intersections, it shall comprise the area bounded by the respective lines of each street and by lines at right angles or normal to the center lines and passing through acute-angled building line corners, or the corners giving the greatest platform area. If the intersection of the center lines falls without the building-line platform, as above described, the said platform shall be increased sufficiently to include the said intersection. When the building-line corner is turned with a curve the platforms above defined shall be indicated upon the map unless herein definitely fixed.

2. Definitions of Elevations Fixing Grades.—Unless otherwise indicated on the map, the elevations shown at a street intersection shall be deemed to be that fixed for the point of intersection of the center lines of both streets affected, or for the center line intersection.

3. Treatment of Center-line Intersection.—The center-line intersection, when it comprises an appreciable area and unless otherwise shown on the map, shall have a uniform elevation at its boundaries, and in determining the elevations for the other platforms herein described, the center-line intersection referred to as a basis of calculation shall be deemed to be the nearest point on the center line of each street at the boundary of the said platform.

4. Treatment of Platform for Streets Having a Light Grade.—If the grade of each of the intersecting streets is 3 per cent. or less, as determined by calculating the rate between the established elevations, the elevation of the center lines of each street within the limits of the curb-line platform shall be the same as that fixed for the center-line intersection. The elevation of

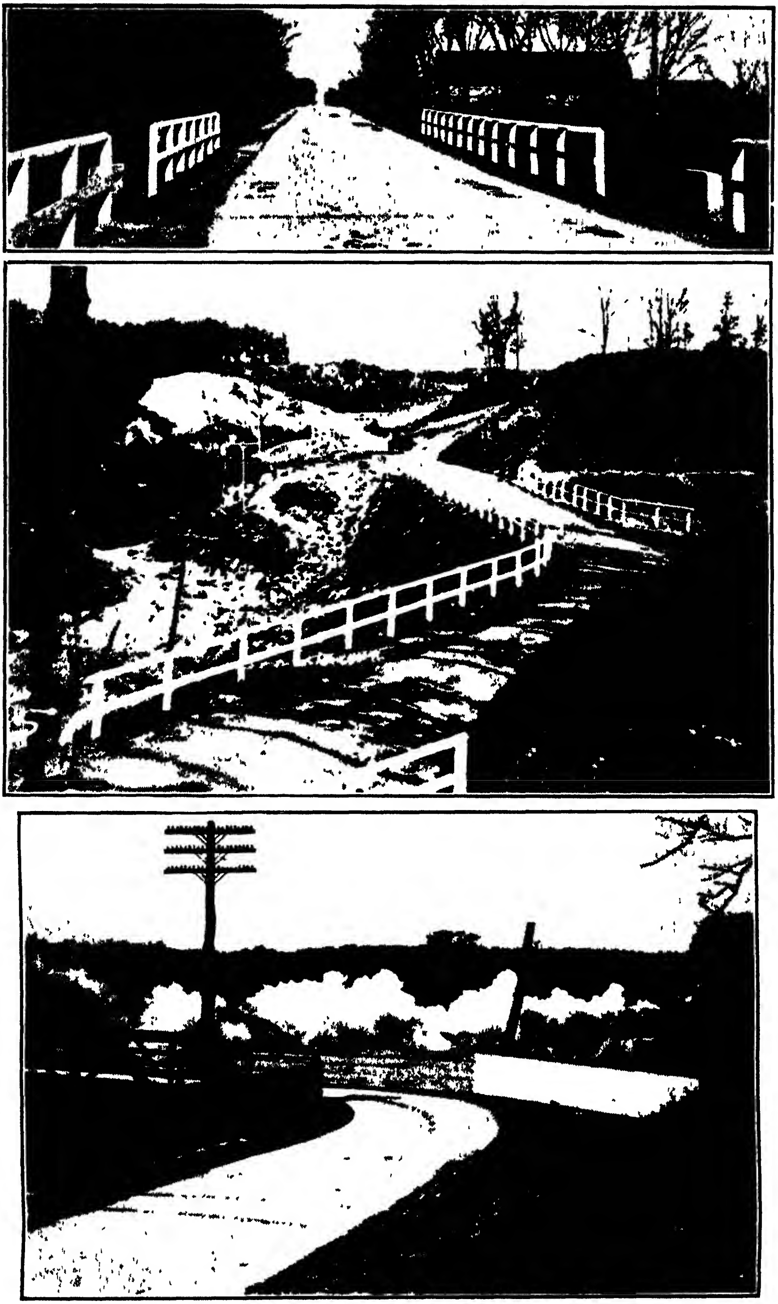


FIG. 113.—Showing design and use of guard fences.

the curbs shall be determined as indicated in Paragraph 8. Provided, however, that the difference in the elevation of points on the center lines opposite any building-line corner, shall not provide a greater transverse sidewalk slope than that fixed as the maximum in Paragraph 7, in which latter event the building-line platform shall be used and the grades of that portion of the streets adjoining the said corners shall be flattened between the boundaries of the building-line platform and the center-line intersection, as provided in Paragraph 5 (*a*).

5. Treatment of Platform for Streets Having a Steep Grade or Meeting at an Acute-angled Intersection.—(*a*) If the grade of any portion or portions of intersecting streets adjoining a building-line corner is over 3 per cent., as calculated between the established elevations, or if a further flattening of the platform grade is required to provide proper sidewalk slopes, for any part of an intersection described in Paragraph 4, the grades of the said portion or portions of each street shall be reduced between the boundaries of the building-line platform and the center-line intersection as follows: If the intersecting streets are of the same width, the grade of the street traversing the shorter block length adjoining the intersection shall be reduced one-third and that of the street traversing the longer block shall be reduced two-thirds. In case the streets have different widths, the grade of the wider street shall be reduced one-third and that of the narrower street two-thirds between the above limits. All grades less than 3 per cent. which are not herein required to be flattened shall be applied at the same rate as originally computed between established elevations. Provided, that in no case shall the maximum platform and sidewalk slopes fixed in Paragraphs 6 and 7 be exceeded.

Any excess in grade over that allowed in Paragraph 7 shall be removed by further flattening, as follows:

(*b*) Special flattening of platform grades for extreme cases of steep grades or acute-angled intersections. If the difference in elevation tentatively fixed for points on the center lines of intersecting streets opposite any building-line corner, after applying the minimum and up to the maximum transverse sidewalk slope on the higher and lower sides respectively, exceeds the maximum transverse sidewalk grades hereinbefore described, the elevation of each street at the boundary of the building-line platform shall be adjusted to remove the excess, the adjustment

of each of the said elevations being directly proportional to the grade of each as originally flattened or applied.

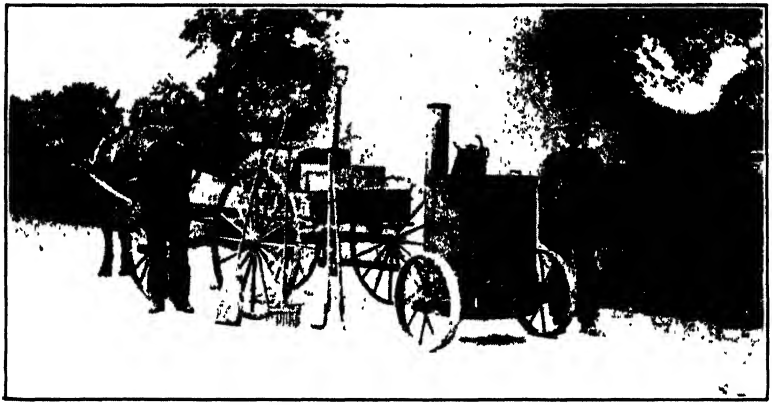
For all cases covered by Paragraphs (*a*) and (*b*) the elevations at the intersections of the center line of each of the narrower streets or at the streets traversing the longer blocks, if they are of equal width, with the curb-line platform of the intersected street shall be the same as the elevation of a point on the center line of the intersected street immediately opposite the first-named intersection, except that the elevation at this point shall be abandoned when the grade along the center line between

Fig. 114.—A patrolman on a Maryland road.

the curb-line platform and the building-line platform exceeds the grade as originally computed.

The grades of the center line of the wider street or of the street traversing the shorter block, if they are of equal width, shall be uniform between the exterior boundaries of the building-line platform and the center-line intersection, except that the maximum platform slope hereinafter fixed shall not be exceeded. The grades of the center line of the narrower street or of the street traversing the longer block, if they are of equal width, shall be uniform between the elevations fixed at the exterior boundaries of the curb-line platform, and also between the latter point and the center-line intersection.

6. Maximum Platform Grades.—The maximum allowable grade along the center line between the curb-line platform and the center-line intersection shall be at the rate of 4 per cent., unless otherwise indicated on the map.



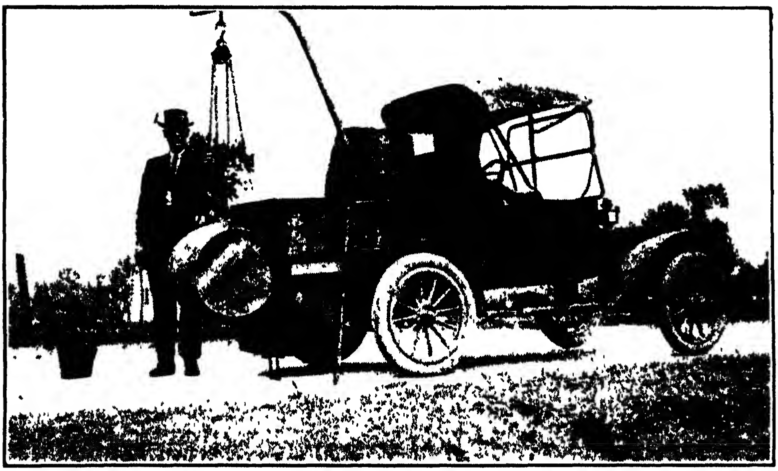


Fig. 115.—Patrol outfits Illinois State Highway Department.

The grades along the center line between elevations established within the limits of a building-line platform shall be uniform, subject only to the flattening provided for in Paragraph 5 (*b*).

7. Transverse Sidewalk Grades.—Whenever practicable, the sidewalk shall slope upward in a direction at right angles to the curb toward the building line at the rate of 2 per cent.

The elevation of the sidewalk at the building-line corner shall be determined by applying this rate to the elevation of the curb giving the higher building-line elevation, at a point immediately opposite the corner, unless the resulting grade on the lower side exceeds 6 per cent., in which case the sidewalk shall be level on the higher side and a greater transverse sidewalk slope up to the maximum shall be used on the lower side.

The maximum transverse sidewalk slope shall be 6 per cent., except in those cases where the street grade as originally computed on any street adjoining a building corner is more than 6 per cent., when the maximum slope shall be 10 per cent. for either street, opposite the said corner. In no case shall the sidewalk at the building line be lower than that of a point immediately opposite it on the curb.

If the transverse sidewalk slope at the building-line corner is more or less than 2 per cent., it shall be made to agree with this latter rate at a point distant 25 ft. from the building-line corner.

8. Curb Elevations.—The relation between the elevation of the center lines and of the top of the curbs at points immediately opposite it at the boundary of and outwardly from the building-line platform shall be as follows: For roadway widths of 24 ft. or less the top of the curbs shall be 0.1 ft. higher than the center line. For roadway widths ranging from 24 ft. up to and including 34 ft. the top of the curbs and the center line shall be at the same elevation. For roadway widths ranging from 34 ft. up to and including 44 ft. the top of the curbs shall be 0.1 ft. lower than the center line. For roadway widths ranging from 44 ft. up to and including 54 ft. the top of the curbs shall be 0.2 ft. lower than the center line, and for roadway widths ranging from 54 ft. up to and including 64 ft. the top of the curbs shall be 0.3 ft. lower than the center line.

The elevation of the intersection of the curb tangents shall be determined from a point immediately opposite on the center line of the wider street or the street traversing the shorter block, if they are of equal width, subject, however, to the same correction in elevation between the top of the curbs and the center line as herein provided.

9. Depth of Gutters.—Whenever practicable a standard depth of gutter of 0.4 ft. shall be used.

10. Curb Grades at Corners.—The tangents in the curbs shall be graded uniformly between the elevations established for them

at the boundaries of the building-line platform and at the intersection of the curb tangents. The curve formed in the curb joining the tangents shall follow a uniform grade between the elevations of the curb tangents at the points of curve.

Fig. 116.—Camp for convicts on highway construction.

11. Grades between Platforms.—The grades of the center line and of the curbs between the elevations computed at platform intersections, or between a platform and an intermediate established elevation, shall be uniform.

CHAPTER XX

TESTS FOR BITUMINOUS ROAD AND PAVING MATERIALS

The following methods of testing are those commonly employed for bituminous materials. Those marked with an asterisk have been adopted by the American Society for Testing Materials, or proposed for adoption. Those proposed by the special Committee of the American Society of Civil Engineers are indicated thus (†). Others are employed by the U. S. Office of Public Roads and Rural Engineering, or are special tests as indicated by the several footnotes.

MELTING POINT (*Cube Method*)*

The melting point of a bituminous material is not clearly defined as a rule and this test determines an arbitrary temperature which is significant for comparisons and is in reality a softening point.

The material whose melting point is to be determined, is melted and poured into a mould that will make a ½-in. cube. The mould is of brass and is carefully amalgamated to prevent the material from sticking to it. The sample and mould are immersed in ice water for about 20 min. A No. 10 gage wire 6 in. long is bent at right angles for a length of ¾ in. at one end, and the short end of the wire is thrust through the center of the cube so that one of the diagonals of the vertical face of the cube is parallel to the long part of the wire. A piece of white paper is placed in the bottom of a bottle about 2 in. in diameter and 4 in. high. The long part of the wire is passed through the cork of the bottle so that the lower edge of the cube will be within 1 in. of the bottom of the bottle. A thermometer is also passed through the cork so that the bulb is near the cube. The bottle is placed in a water or oil bath and the temperature of the bath is raised at a rate of 3° to 6°C. a minute. The sample gradually softens and finally flows off the wire. The melting point is the temperature shown

by the thermometer inside the bottle at the time that the material touches the paper in the bottom of the bottle.

SOFTENING POINT (*Ring and Ball Method*)*

Apparatus.—Brass ring 15.875 mm. (5/8 in.) in diameter, 6.35 mm. (1/4 in.) deep, 2.3825 mm. (3/32 in.) wall, suspended 25.40 mm. (1 in.) above bottom of beaker. Steel ball 9.525 mm. (3/8 in.) in diameter, weighing between 3.45 grams and 3.50 grams. Standardized thermometer. Glass beaker, approximately 600 c.c. capacity.

Operation.—Carefully melt sample and fill ring with material to be tested. Remove any excess. Place ball in center of ring and suspend in beaker containing approximately 400 c.c. of water at a temperature of 5°C. (41°F.). Arrange thermometer bulb within 1/2 in. of sample and at same level. Apply heat uniformly over bottom of beaker in quantity sufficient to raise temperature 5°C. (9°F.) per minute. Record temperature at starting test and every minute thereafter until test is completed. (Rate of heating is very important.) Softening point is temperature at which specimen has dropped 1 in. Successive tests should average within 3°C. For temperatures above 95°C., glycerine shall be used instead of water.

FLOW POINT[1]

This test is similar in character to the melting-point test and is used as a ready means of determining the relative consistency of paving cements, particularly the different mixes for the same job and presumably of the same consistency. It may also be used to determine with a fair degree of accuracy the distance each of several paving cements will flow in a given time. Care must be taken to maintain the plates at a uniform temperature throughout the period and to have all parts of the plate at the same temperature.

The test is made by moulding cylinders of the paving cement in a brass collar that is 3/8 in. in diameter and 3/4 in. long. The cylinders are pressed onto the flow plates until they adhere and then immersed in water until they all come to the same temperature. The plate is then set at an angle of 45° to the hori-

[1] See "The Modern Asphalt Pavement," by Clifford Richardson.

zontal on a wooden support, which has been covered with asbestos, in the Freas oven which has been heated to the required temperature, usually 160°F. When any one of the cylinders has flowed to the bottom of the plate, the plate is removed from the oven and the distance each has flowed is measured. The time during which the flow took place is also recorded, *i.e.*, the time the plate was in the oven. For very hard cements a higher temperature may be used.

SPECIFIC GRAVITY†

The specific gravity is usually determined by means of a wide-mouth pycnometer, by displacing distilled water with an equal volume of the material whose specific gravity is desired. The temperature of the water and the bituminous material must be carefully maintained during the test. The standard temperature for bituminous road materials is 25°C. The method is applicable to other materials of a viscous nature, but the temperature may be other than is used for road materials.

Care must be taken to prevent air bubbles forming in the material as it is poured into the pycnometer, but usually no difficulty is encountered if they are heated until quite fluid.

The clean, dry pycnometer with stopper is first weighed empty and this weight called W_1. It is then filled with freshly distilled water at 25°C. in the usual manner, the weight again taken and called W_2. The bitumen should be brought to a fluid condition by the gentle application of heat, care being taken that no loss by evaporation occurs. When sufficiently fluid, enough is poured into the pycnometer, which may also be warmed, to about half fill it, without allowing the material to touch the sides of the tube above the desired level. If the presence of air bubbles is suspected, the pycnometer may be agitated gently, or it may be necessary to place the tube and contents in the oven for a few minutes. The tube and contents are cooled at 25°C. for at least 20 min. in any suitable manner and weighed with the stopper. This weight is called W_3. Distilled water at 25°C. is then poured in until the pycnometer is full, the stopper inserted and the whole weighed. This weight is called W_4. From the weights obtained the specific gravity of the bitumen may be calculated as follows:

$$\text{Specific gravity} = \frac{W_3 - W_1}{(W_2 - W_1) - (W_4 - W_3)}$$

The following method is adapted for fluid oils, such as fluxes, dust layers and creosotes:

The material whose specific gravity is to be determined is poured into a tin cup and placed in a water bath maintained at the proper temperature, which is usually 25°C. for road oils and 38°C. for creosote oils. The material in the cup is stirred with the thermometer until it comes to the proper temperature and is then poured into a hydrometer jar. The hydrometer is then placed in the liquid and given sufficient time to come to rest in the viscous liquid and the specific gravity read from the graduation at the surface of the liquid. A second reading should be taken and the hydrometer be pushed down a few scale divisions and if it fails to rise to the original reading the liquid is too viscous for the method.

The Westphal balance is sometimes used for determining the specific gravity of fluid oils.

The specific gravity of solid material is most readily determined by suspending a lump of the material from the balance by means of a silk thread and weighing first in air and then in distilled water at the proper temperature. It should be allowed to rest in the water about five minutes so as to come to the temperature of the water. The lump should weigh in air, 1 or 2 grams. If the material has a specific gravity less than unity a 1- or 2-gram scale weight may be suspended with the sample to cause it to sink, suitable corrections being made.

PENETRATION*

Definition.—The consistency of a bituminous material is expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. Where the conditions of test are not specifically mentioned, the load, time and temperature are understood to be 100 grams, 5 sec., 25°C. (77°F.) and the units of penetration to indicate hundredths of centimeters.

APPARATUS

The container for holding the material to be tested shall be a flat-bottom, cylindrical dish, 55 mm. (2$\frac{3}{16}$ in.) in diameter and 35 mm. (1$\frac{3}{8}$ in.) deep.

The needle for this test shall be of cylindrical steel rod 50.8

mm. (2 in.) long and having a diameter of 1.016 mm. (0.04 in.) and turned on one end to a sharp point having a 6.35-mm. (¼-in.) taper.

The water bath shall be maintained at a temperature not varying more than 0.1°C. from 25°C. (77°F.). The volume of water shall be not less than 10 liters and the sample shall be immersed to a depth of not less than 10 cm. (4 in.) and shall be supported on a perforated shelf not less than 5 cm. (2 in.) from the bottom of the bath.

Any apparatus which will allow the needle to penetrate without appreciable friction, and which is accurately calibrated to yield results in accordance with the definition of penetration, will be acceptable.

The transfer dish for container shall be a small dish or tray of such capacity as will insure complete immersion of the container during the test. It shall be provided with some means which will insure a firm bearing and prevent rocking of the container.

Preparation of Sample.—The sample shall be completely melted at the lowest possible temperature and stirred thoroughly until it is homogeneous and free from air bubbles. It shall then be poured into the sample container to a depth of not less than 15 mm. (⅝ in.). The sample shall be protected from dust and allowed to cool in an atmosphere not lower than 18°C. (65°F.) for 1 hr. It shall then be placed in the water bath along with the transfer dish and allowed to remain 1 hr.

Testing.—In making the test the sample shall be placed in the transfer dish filled with water from the water bath of sufficient depth to completely cover the container. The transfer dish containing the sample shall then be placed upon the stand of the penetration machine. The needle, loaded with specified weight, shall be adjusted to make contact with the surface of the sample. This may be accomplished by making contact of the actual needle point with its image reflected by the surface of the sample from a properly placed source of light. Either the reading of the dial shall then be noted or the needle brought to zero. The needle is then released for the specified period of time, after which the penetration machine is adjusted to measure the distance penetrated.

At least three tests shall be made at points on the surface of the sample not less than 1 cm. (⅜ in.) from the side of the container and not less than 1 cm. (⅜ in.) apart. After each

test the sample and transfer dish shall be returned to the water bath and the needle shall be carefully wiped toward its point with a clean, dry cloth to remove all adhering bitumen. The reported penetration shall be the average of at least three tests whose values shall not differ more than four points between maximum and minimum.

When desirable to vary the temperature, time and weight, and, in order to provide for a uniform method of reporting results when variations are made, the samples shall be melted and cooled in air as above directed. They shall then be immersed in water or brine, as the case may require, for *one hour* at the temperature desired. The following combinations are suggested:

at 0°C. (32°F.) 200-gram weight, 60 sec.
at 46.1°C. (115°F.) 50-gram weight, 5 sec.

THE FLOAT TEST†

The apparatus consists of an aluminum saucer into which a brass sleeve may be screwed. A small quantity of the material to be tested is heated in a metal spoon until quite fluid, with care that it suffers no appreciable loss by volatilization and that it is kept free from air bubbles. It is then poured into the collar in a thin stream until slightly more than level with the top. The surplus may be moved, after the material has cooled to room temperature, by means of a spatula blade which has been slightly heated. The collar and plate are then placed in a tin cup containing ice water maintained at 5°C., and left in this bath for at least 15 min. Meanwhile another cup is filled about three-fourths full of water and placed on the tripod, and the water is heated to any desired temperature at which the test is to be made. This temperature should be accurately maintained, and the saucer with the brass collar in place is floated on the surface of the water and the time required to melt out the plug of bituminous material is taken with a stop watch. This test is more frequently employed with tars than with asphalts. The temperature may be 32°C., 50°C., or 100°C.

DUCTILITY*

The ductility test is made both on asphalt cements and road binders and upon the bitumen extracted from these materials or

from paving mixtures. The ductility is the distance in centimeters that a standard briquette of the material will elongate before breaking. The sample to be tested should be heated gently until fluid and should then be stirred carefully to insure that it is homogeneous. The mould is then filled, and excess being poured in to allow for shrinkage during cooling. When cool the briquette is trimmed to the mould with a hot spatula. The briquette is placed in a water bath maintained at 25°C. for at least 20 min. The test is then made in one of the machines designed for the purpose. The rate of elongation should be 5 cm. per minute and the temperature of the water bath must be within ½°C. of the standard which is 25°C.

LOSS ON HEATING*

The amount lost by oils and asphaltic compounds when they are heated in an oven at a temperature of 163°C. (325°F.) plus or minus 1°C. shall be determined by heating fifty (50) grams of the water-free substance contained in a flat-bottom dish, the inside dimensions of which are approximately 55 mm. (2 3/16 in.) in diameter, by 35 mm. (about 1 3/8 in.) deep (3 oz. Gill-style ointment box, deep style) for 5 hr.

The oven in which the substance is to be heated shall be brought to the prescribed temperature before the sample is introduced, and the temperature of the sample under test shall be regarded as that of a similar quantity of the same material immediately adjoining it in the oven, in which the bulb of a standardized thermometer is immersed.

The oven may be either of circular or rectangular form and the source of heat either gas or electricity.

The samples under test shall rest in the same relative position in a single row upon a perforated circular shelf 24.8 cm. (9.75 in.) in diameter, suspended by a vertical shaft midway in the oven which is revolved by mechanical means at the rate of from 5 to 6 revolutions per minute.

NOTE.—If additional periods of heating are desired, it is recommended that they be made in successive increments of 5 hr. each.

If the residue after heating is to be tested for penetration, the sample should be thoroughly mixed by stirring until it is cool, and thereafter manipulated in accordance with the directions of the Standard Test for Penetration of Bituminous Materials.

SPECIFIC VISCOSITY†

The viscosity of fluid bituminous road binders may be determined at any desired temperature by means of the Engler viscosimeter.

As all viscosity determinations are recorded as relative to that of water, the viscosimeter should be calibrated as follows: The cup and outlet tube should first be scrupulously cleaned by means of a soft cloth. The stopper is then inserted in the tube and the cup filled with water at 25°C. to the top of the projections. The measuring cylinder is placed directly under the outflow tube so that the material, upon flowing out, will not touch the sides, and the stopper is then removed. The time required for 50 c.c. of water should be about 11 sec. and for 100 c.c. about 22.8 sec.

Bituminous road materials are tested in the same manner as water and the temperature at which the test is made is controlled by the bath. The material should be brought to the desired temperature and maintained there for at least 30 min. before making the test. The results are expressed as specific viscosity compared with water at 25°C., as follows:

$$\left.\begin{array}{c}\text{Specific viscosity}\\ \text{at A°C.}\end{array}\right\} = \frac{\text{Seconds for passage of given volume at A°C.}}{\text{Seconds for passage of same volume of water at 25°C.}}$$

The temperatures commonly employed for this test are 25°C. and 50°C.

TOTAL BITUMEN AND FREE CARBON†

Dissolve 2 grams of the material to be tested in 100 c.c. of carbon disulphide and set aside for 15 min. In dissolving the material add a small amount of the carbon disulphide to the sample of material which has been weighed in a 150-c.c. Erlenmeyer flask and shake until the lump of material is dissolved, then add the remainder of the disulphide. The insoluble portion is determined by filtering the solution through a Gooch crucible fitted with an asbestos pad.

The asbestos pad in the Gooch crucible is made as follows: Beat a quantity of long-fiber amphibole asbestos in a mortar until well broken and then place in a large bottle and cover with distilled water and shake thoroughly. Place the Gooch crucible in a filter tube and pour a small quantity of the mixture from the bottle into the crucible and apply light suction. Add asbestos

until the holes in the crucible show but dimly through the pad when the crucible is held to the light. Dry the crucible to constant weight and record the weight.

Filter the solution of compound and carbon disulphide through the crucible and again dry to constant weight. This is accomplished by placing the crucible on top of an oven until the bisulphide has evaporated and then placing it in the oven at 100°C. for 20 min. The crucible should then be cooled in a desiccator and weighed. Then ignite the crucible until all carbon is burned off and weigh again. The difference between the second and third weights is "free carbon" if the compound was a tar. If an asphalt is being tested the weight of the sample minus the difference between the first and second weights is "total bitumen." The difference between the first and third weights is "ash" which should also be noted.

FIXED CARBON†

The determination is made in accordance with the method described for coal in the *Journal of the American Chemical Society*, 1899, volume 2, page 116 and is as follows: 1 gram of the material is placed in a platinum crucible weighing from 20 to 30 grams and having a tightly fitting cover. It is then heated for 7 min. over the full flame of a Bunsen burner. The crucible should be supported on a platinum triangle with the bottom of the crucible from 6 to 8 cm. above the top of the burner. The flame should be fully 20 cm. high when burning freely and the determination should be made in a place free from drafts. The upper surface of the cover should burn clear, but the under-surface should remain covered with carbon, excepting in the case of some of the more fluid bitumens, when the under-surface of the cover may be quite clean.

The crucible is removed to a desiccator and when cool is weighed, after which the cover is removed and the crucible is placed in an inclined position over the Bunsen burner and ignited until nothing but ash remains. Any carbon deposition on the cover is also burned off. The weight of the ash remaining is deducted from the weight of the so-called fixed or residual carbon, which is calculated on a basis of the total weight of the sample, exclusive of mineral matter. Owing to sudden expansion in burning some of the more fluid bitumens, it is well to

hold the cover down with the end of the tongs until the most volatile products have burned off.

SOLUBILITY IN 86° NAPHTHA†

(Asphaltene Determination)

This determination is made in the same manner as its total bitumen except that the solvent is naphtha having a gravity of 86° on the Beaumé scale. This solvent is exceedingly volatile and it must always be tested as to gravity before being used.

The insoluble portion of the material is calculated in percentage of the bitumen in the material and the constituent compounds are called asphaltenes.

SOLUBILITY IN CARBON TETRACHLORIDE†

(Carbene Determination)

The test is made exactly in the same manner as the test for total bitumen, except that the solvent is carbon tetrachloride. The percentage of bitumen insoluble is calculated as a percentage of the total bitumen in the material, and the compounds that constitute the insoluble residue are called carbenes.

ANALYSIS OF FLUXES

The properties of fluxes are determined in exactly the same manner as are similar properties of other bituminous materials.

The number of such properties determined will depend upon the purpose of the examination. For ordinary purposes the following properties are determined:

Specific gravity
Flash point
Viscosity
Loss on heating
Fixed carbon
Paraffine scale
Solubility in carbon disulphide
Solubility in carbon tetrachloride

DISTILLATION*

Sampling.—The sample as received shall be thoroughly stirred and agitated, warming, if necessary, to insure a complete mixture before the portion for analysis is removed.

Dehydration.—If the presence of water is suspected or known, the material shall be dehydrated before distillation. About 500-c.c. of the material is placed in an 800-c.c. copper still provided with a distilling head connected with a water-cooled condenser. A ring burner is used, starting with a small flame at the top of the still, and gradually lowering it, if necessary, until all the water has been driven off. The distillate is collected in a 200-c.c. separatory funnel with the tube cut off close to the stopcock. When all the water has been driven over and the distillate has settled out, the water is drawn off and the oils returned to the residue in the still. The contents of the still shall have cooled to below 100°C. before the oils are returned, and they shall be well stirred and mixed with the residue.

Apparatus.—The apparatus shall consist of the following standard parts:

(*a*) *Flask.*—The distillation flask shall be a 250-c.c. Engler distilling flask, having the following dimensions:

Diameter of bulb	8 0 cm.
Length of neck	15 0 cm.
Diameter of neck	1 7 cm.
Surface of material to lower side of tubulature	11 0 cm.
Length of tubulature	15 0 cm.
Diameter of tubulature	0 9 cm.
Angle of tubulature	75°

A variation of 3 per cent. from the above measurements will be allowed.

(*b*) *Thermometer.*—Thermometer is to be made of resistance glass and to be filled with CO_2 under pressure of one atmosphere at 300°C., and to be provided with an expansion bulb at the top. It is to be annealed at 400°C. for 96 hr. and slowly cooled. It shall be graduated in single degrees Centigrade from minus 5° to plus 400° and the length of the graduations from 0° to 400° to be 300 mm., plus or minus 10 mm. The diameter of stem is to be 7 mm., plus or minus 1 mm. When the thermometer is at a temperature of 26°C., and plunged into a free flow of steam, the meniscus shall pass the 90° mark in not less than 6 sec.

The thermometer shall be set up as for the distillation test, using water, naphthalene and benzophenone as distiiling liquids. The correctness of the thermometer shall be checked at 0°C. and 100°C. after each third distillation until seasoned.

Condenser.—The condenser tube shall have the following dimensions:

Adaptor	70 mm.
Length of straight tube	185 mm.
Width of tube	12–15 mm.
Width of adaptor end of tube	20–25 mm.

Stands.—Two iron stands shall be provided, one with a universal clamp for holding the condenser, and one with a light grip arm with a cork-lined clamp for holding the flask.

Burner and Shield.—A Bunsen burner shall be provided, with a tin shield 20 cm. long by 9 cm. in diameter. The shield shall have a small hole for observing the flame.

Cylinders.—The cylinders used in collecting the distillate shall have a capacity of 25 c.c., and shall be graduated in tenths of a cubic centimeter.

Setting up the Apparatus.—The apparatus shall be set up with the thermometer placed so that the top of the bulb is opposite the middle of the tubulature. All connections should be tight.

Method.—One hundred cubic centimeters of the dehydrated material to be tested shall be placed in a tared flask and weighed. After adjusting the thermometer, shield, condenser, etc., the distillation is commenced, the rate being so regulated that 1 c.c. passes over every minute. The receiver is changed as the mercury column just passes the fractionating point.

The following fractions should be reported:

Start of distillation	to	110°C.
110°C.	to	170°C.
170°C.	to	235°C.
235°C.	to	270°C.
270°C.	to	300°C.
Residue.		

To determine the amount of residue, the flask is weighed again when distillation is complete. During the distillation the condenser tube shall be warmed when necessary to prevent the deposition of any sublimate. The percentages of fractions should be reported both by weight and by volume.

FLASH POINT AND BURNING POINT†

Open-cup Method.—The apparatus consists of a brass cup of about 50 c.c. capacity which is supported inside a larger brass

cup in such a manner that the smaller cup may be entirely surrounded with a bath of cotton seed oil or paraffine. The two cups are usually supported on a tripod which carries a rod from which the thermometer is hung with the bulb immersed in the material to be tested.

In performing the test the bath is filled and the vessel containing the sample is placed on the bath with the thermometer in position. The sample is heated at the rate of about 5°C. per minute and is tested from time to time by means of a very small gas flame. The testing flame is obtained by drawing down a piece of glass tubing to form a tube about 5 mm. in diameter and using it for a burner thus securing a thin flame about ½ in. long. The testing flame is passed over the surface of the sample and a slight distance from it from time to time and when a bluish flame spreads entirely over the surface the flash point has been reached and the temperature is taken.

If the burning point is also desired, the heating is continued and the testing with the gas flame repeated until a flame is maintained over the surface of the sample after the testing flame is removed. This is the burning point and the temperature is taken.

Closed-cup Method.—For this method a brass cup containing about 300 c.c. is used which is provided with a glass cover in which is one hole for inserting the thermometer and one for the testing flame. The surface of sample to be tested is about ½ in. below the glass cover. The cup is provided with an oil bath similar to that which was described for the open-cup method. The test is made as for the open-cup method, the testing flame being inserted through the small hole in the glass cover. The indication of the flash point is the same as in the open-cup method.

With either method the test must be made in a place free from draughts and the rate of heating must be carefully controlled.

DETERMINATION OF AMOUNT OF BITUMEN IN A SHEET ASPHALT OR ASPHALTIC-CONCRETE PAVING MIXTURE

The Centrifugal Method.—The aggregate is prepared for analysis by heating until it is sufficiently soft to be thoroughly disintegrated by means of a large spoon. The disintegrated aggregate is then allowed to cool, after which a sufficient amount is taken to yield, on extraction, from 30 to 50 grams of bitumen. About 300 grams of a sheet-asphalt mixture and 500 grams of an

asphaltic-concrete mixture should be used. The sample is placed in the bowl of the centrifugal machine, and a ring ¾ in. wide, cut from felt paper, is fitted on the rim, after which the cover plate is placed in position and drawn down tightly. If the bitumen is to be recovered and examined, the felt ring should be previously treated in the empty extractor with a couple of charges of carbon disulphide in order to remove any small amount of grease or resin that may be present, although a proper grade of felt should be practically free from such products. The bowl is now placed on the motor shaft and an empty bottle is placed under the spout. One hundred fifty cubic centimeters of carbon disulphide is poured into the bowl through the funnel. After allowing the material to digest for a few minutes the motor is started, slowly at first in order to permit the aggregate to distribute uniformly. The speed should then be increased sufficiently by means of the regulator to cause the dissolved bitumen to flow from the spout in a thin stream. When the first charge has drained, the motor is stopped and a fresh portion of disulphide is added. This operation is repeated from four to six times with 150 c.c. of disulphide. With a little experience the operator can soon gage the amount for any given material. When the last addition of solvent has drained off, the bowl is removed and placed with the cover plate uppermost on a sheet of manila paper. The cover plate and felt ring are carefully laid aside on the paper and, when the aggregate is thoroughly dry, it can be brushed on a pan of the rough balance and weighed. The difference between this weight and the original weight is the amount of bitumen extracted plus such mineral aggregate as is carried through the felt by the solvent.

Some of the finer portion of the mineral aggregate will be carried through the felt ring and into the extracted material. To correct for this the extract is evaporated until only the bitumen is left. This is then burned and the residue added to the mineral aggregate and suitable correction in the quantity of bitumen thereby made.

New York Extractor Method.[1]—If a bituminous concrete mixture is being tested, the sample is warmed until it can be readily broken apart without fracturing any of the stony fragments. Five hundred grams of the material is placed in the wire basket of the extractor and packed as tightly as may be. The surface

[1] Method of New York Testing Laboratory.

is covered with cotton waste to a depth of about ¼ in. One hundred seventy-five cubic centimeters of carbon disulphide is placed in the inside vessel in which the wire basket is suspended. The heat is then turned on and the condenser put in place and water circulation started. The extraction requires 5 to 10 hr. If sheet asphalt or Topeka mixture is being extracted 200 or 300 grams is sufficient. The correction for the fine material that passes with the bitumen is made as in the centrifugal method.

Filtration Method.[1]—The amount of bitumen in a sheet asphalt or Topeka surface mixture may be determined as follows: A funnel 2½ in. in diameter with a short stem is placed in an assay flask. The mixture to be examined is broken up and placed in the funnel which has been fitted with an S and S 597 filter paper. Sufficient carbon disulphide is added to moisten the mixture and after a few minutes the mixture is covered with bisulphide to within ⅛ in. of the top of the filter paper. As the bisulphide passes through more is added until the sand is clean. The apparatus is allowed to stand over night and on the following day the filter is removed from the flask without disturbing its contents, and placed in a fresh flask. The filtrate is decanted into another flask, care being taken not to disturb the sediment. The solution thus decanted is burned and correction made for any ash obtained. The first flask used is washed out onto the filter which is treated with bisulphide until clean. The mineral matter is scraped off the filter paper into a clean dish, dried and weighed. The filter paper is burned and the correction added to the weight of the contents of the dish along with the correction from the flask.

WATER-SOLUBLE MATERIALS

Boil gently 2 grams of material with 25 c.c. of distilled water for 1 hr. Filter and wash with 25 c.c. of boiling water. Evaporate filtrate in weighed dish to dryness and constant weight at 105°C. Weigh residue. Ignite residue and weigh again, giving weight of inorganic matter plus weight of crucible. Weight No. 2 minus weight No. 3 gives weight of organic matter and the water-soluble material is thus determined.

PARAFFINE DETERMINATION (*Holde Method*)

The determination of the amount of paraffine requires exceedingly faithful observance of the details as outlined below. The

[1] "The Modern Asphalt Pavement," Clifford Richardson.

distillation should be carried out rapidly and in a retort with a short neck so that the distillate will pass quickly to the condensing tube.

One hundred grams of the material upon which the test is to be made is distilled rapidly to dry coke. Five grams of the distillate is placed in a 60-c.c. flask and thoroughly mixed with 25 c.c. of Squibbs absolute ether. Twenty-five cubic centimeters of Squibbs absolute alcohol is then added and the flask packed in a mixture of finely broken ice and salt in which it must remain for at least 30 min. at a temperature of $-17°C$.

Meanwhile a filter is prepared employing 9 cm. No. 575 S. & S. hardened filter paper and after the flask has been in the freezing bath for a sufficient time the contents are filtered quickly, using suction. The flask and filter are then washed with about 50 c.c. of a mixture of equal parts of Squibbs ether and Squibbs alcohol which has been cooled to $-17°C$. The wax precipitate remaining in the filter paper is then transferred to a watch crystal placed on a steam bath and dried and the paraffine on the crystal weighed and the percentage calculated.

TESTS FOR CREOSOTE OILS

Distillation.[1]—The apparatus for distilling the creosote must consist of a stoppered glass retort having a capacity, as nearly as can be obtained, of eight (8) ounces up to the bend of the neck, when the bottom of the retort and the mouth of the off-take are in the same plane. The bulb of the thermometer shall be placed one-half (½) inch above the liquid in the retort at the beginning of the distillation, and this position must be maintained throughout the operation. A condensing tube shall be attached to the retort by a tight cork joint. The distance between the thermometer and the end of the condensing tube shall be twenty-two (22) inches, and during the progress of the distillation the tube may be heated to prevent the congealing of the distillate. The upper third of the retort and at least two (2) inches of the neck must be covered with a shield of heavy asbestos paper during the entire process of distillation, so as to prevent heat radiation, and there must be placed between the bottom of the retort and the flame of the lamp or burner two (2) sheets of wire gauze, each twenty (20) mesh fine and at least six (6) inches square. The flame must be protected against air currents.

[1] Method of American Railway Engineering Assn.

The distillation shall be continuous and uniform, the heat being applied gradually. It shall be at a rate approximating one (1) drop per second, and shall take the thirty (30) to forty (40) minutes after the first drop of distillate passes into the receiving vessel. The distillates shall be collected in weighed bottles and all percentages determined by weight in comparison with the dry oil. One hundred (100) grams of the oil shall be used for the test.

Determination of Tar Acids.—Place 10 c.c. of the distillate between 250° and 315°C. in a beaker and add fifteen (15) c.c. of a 15 per cent. caustic soda solution. Heat the mixture to 100° C. for 30 min., stirring the liquid frequently; then pour it into a small separatory funnel and allow it to stand until the alkaline solution and oil have separated. Draw off the alkaline liquid into a Babcock milk bottle and return the oil to the beaker. Treat this oil as before, using only 10 c.c. of caustic soda. After allowing the two liquids to separate add this alkaline solution to the other in the milk bottle. Now add to the combined alkaline solutions in the milk bottle sufficient dilute sulfuric acid to make the liquid in the bottle decidedly acid, and if necessary add enough more acid to bring the liquid into the neck of the bottle. Place the bottle in a Babcock machine and centrifuge it for 5 min., at the speed used for testing milk, then read off the amount and calculate the per cent. of acid in the distillate.

Saponification Test.—Pour ten cubic centimeters (10 c.c.) of distillate between 250° and 315°C. into a Babcock's milk bottle and add twice the amount of concentrated sulphuric acid. After shaking the bottle until the oil and acid are thoroughly mixed, place the bottle on a water bath and keep it at a temperature of boiling water for 1 hr. At frequent intervals (say every 10 min.) shake the bottle vigorously, so as to keep the contents well mixed during the time of heating. At the end of the hour add enough concentrated sulphuric acid to bring the liquid into the neck of the bottle.

Place the bottle in a Babcock machine and centrifuge it for 15 min. at the usual speed for estimating butter fat. Read off the amount of unsulphonated oil. If this amount is in excess of 2 per cent. (2%) of the distillate (250° to 315°C.) then draw off the unsulphonated oil into another milk bottle and treat it with a 10 per cent. caustic soda solution, heating and estimating

the amount of unsaponifiable oil in the same manner as described above, using only caustic soda throughout this latter process.

Modified Sulphonation Test.—(Forest Products Laboratory Method.) Pour 10 c.c. of the distillate between 250 and 315°C. into a Babcock milk bottle and add slowly 40 c.c. of N/37 sulphuric acid. The acid should be added 10 c.c. at a time and the bottle shaken for 2 min. after each addition of 10 c.c. of acid. After all the acid has been added the bottle is kept at a constant temperature of 98° to 100°C. for 1 hr. during which time it is shaken vigorously every 10 min. At the end of the hour the bottle is removed from the bath and cooled and filled to the top of the graduations with ordinary sulphuric acid and then whirled in the Babcock machine for 5 min. The unsulphonated residue is read from the graduations and the per cent. calculated.

Specific Gravity.—The specific gravity of creosote oils is readily determined by means of the hydrometer as previously described (page 392).

Solids Insoluble in Benzole or Chloroform.—The determination of the insoluble portion in creosotes is made in the manner previously described for free carbon, the solvent being hot benzole or chloroform.

GLOSSARY

The following words and terms are employed in highway engineering and have been defined by a special committee of the American Society of Civil Engineers or by the American Society for Testing Materials. For many of the words both have agreed on the definition.

Asphalts.—Solid or semi-solid native bitumens, solid or semi-solid bitumens obtained by refining petroleum, or solid or semi-solid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Native Asphalt.—Asphalt occurring as such in nature.

Asphalt-block Pavement.—One having a wearing course of previously prepared blocks of asphaltic concrete.

Asphalt Cement.—A fluxed or unfluxed asphalt specially prepared as to quality and consistency for direct use in the manufacture of bituminous pavements, and having a penetration at 25°C. (77°F.) of between 5 and 250, under a load of 100 grams applied for 5 sec. or,

Asphalt Cement.—A fluxed or unfluxed asphaltic material, especially prepared as to quality and consistency, suitable for direct use in the manufacture of asphaltic pavements, and having a penetration of between 5 and 250

Asphaltenes.—The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements and solid native bitumens, which are soluble in carbon disulphide but insoluble in paraffine naphthas.

Asphaltic.—Similar to, or essentially composed of, asphalt.

Base.—Artificial foundation.

Binder.—A foreign or fine material introduced into the mineral portion of the wearing surface for the purpose of assisting the road metal to retain its integrity under stress, as well as, perhaps, to aid in its first construction. (2) The course in a sheet-asphalt pavement, frequently used between the concrete foundation and the sheet-asphalt mixture of graded sand and asphalt cement.

Bitumens.—Mixtures of native or pyrogenous hydrocarbons and their nonmetallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide.

Bituminous.—Containing bitumen or constituting the source of bitumen.

Bituminous Cement.—A bituminous material suitable for use as a binder having cementing qualities which are dependent mainly on its bituminous character.

Bituminous Concrete Pavement.—One composed of stone, gravel, sand shell, or slag, or combinations thereof, and bituminous materials incorporated together by mixing methods.

Bituminous Emulsion.—A liquid mixture in which minute globules of bitumen are held in suspension in water or a watery solution.

Bituminous Macadam Pavement.—One having a wearing course of macadam with the interstices filled by penetration methods with a bituminous binder.

Bituminous Material.—Material containing bitumen as an essential constituent.

Bituminous Pavement.—One composed of stone, gravel, sand, shell, or slag, or combinations thereof, and bituminous materials incorporated together.

Bituminous Surface.—A superficial coat of bituminous material with or without the addition of stone or slag chips, gravel, sand, or material of similar character.

Blanket.- See "Carpet."

Bleeding.—The exudation of bituminous material on the roadway surface after construction.

Blown Petroleums.—Semi-solid or solid products produced primarily by the action of air upon liquid native bitumens which are heated during the blowing process.

Bond.—The combined action of inertia, friction, and of the forces of adhesion and cohesion which helps the separate particles composing a crust or pavement to resist separation under stress. Mechanical bond is the bond produced almost wholly, in a well-built broken-stone macadam road, by the interlocking of angular fragments of stone and the subsequent filling of the remaining interstices with the finer particles.

Bound.—Bonded.

Brick Pavement.—One having a wearing course of paving bricks, or blocks.

Bridge.—A structure for the purpose of carrying traffic over a gap in the roadbed measuring 10 ft. or more in the clear span.

Camber of a Bridge.—The rise of its center above a straight line through its ends.

Camber of a Road.—See "Crown."

Carbenes.—The components of the bitumen in petroleums, petroleum products, malthas, asphalt cements and solid native bitumens, which are soluble in carbon disulphide but insoluble in carbon tetrachloride.

Carpet.—A bituminous surface of appreciable thickness, generally formed on top of a roadway by the application of one or more coats of bituminous material with gravel, sand, or stone chips added.

Cement—An adhesive substance used for uniting particles of other materials to each other. Ordinarily applied only to calcined "cement rock,' or to artificially prepared, calcined, and ground mixtures of limestone and siliceous materials. Sometimes used to designate bituminous binder used in bituminous pavements, when the expression "bituminous cement" is understood to be meant.

Cemented.—Bonded. Referring to water-bound macadam, the term "cemented" is used to designate that condition existing when, after rolling the stone forming the crust, the remaining voids have been filled with the finer sizes, and the stone dust or "flour" has, under the action of water, taken a "set," as does cement itself.

Cement-concrete.—An intimate mixture of gravel, shell, slag, or broken

stone particles with certain proportions of sand or similar material, cement, and water, made previous to placing.

Cement-concrete Pavement.—One having a wearing course of hydraulic cement-concrete.

Chert.—Compact siliceous rock formed of calcedonic or opaline silica, or both.

Chips.—Small angular fragments of stone containing no dust.

Clinker.—Generally a fused or partly fused byproduct of the combustion of coal, but also including lava and Portland-cement clinker, and partly vitrified slag and brick.

Coal Tar.—The mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal.

Coat.—See "Carpet." (1) The total result of one or more single-surface applications. (2) To apply a coat.

Coke-oven Tar.—Coal tar produced in byproduct coke ovens in the manufacture of coke from bituminous coal.

Consistency.—The degree of solidity or fluidity of bituminous materials.

Course.—One or more layers of road metal spread and compacted separately for the formation of the road or pavement. Courses are usually referred to in the order of their laying as first course, third course, etc. Also a single row of blocks in a pavement.

Crown.—The rise in cross-section from the lowest to the highest part of the finished roadway. It may be expressed either as so many inches (or tenths of a foot), or as a rate per foot of distance from side to center, *i.e.*, "the crown is 4 in.," or "the crown is ½ in. to the foot."

Crusher-run.—The total unscreened product of a stone crusher.

Crusher-run Stone.—The product of a stone crusher, unscreened except for the removal of the particles smaller than remaining on about a ¼-in. screen.

Crust.—That portion of a macadam or similar roadway above the foundation consisting of the road metal proper with its bonding agent or binder.

Culvert.—A structure for the purpose of carrying traffic over a gap in the roadbed, measuring less than 10 ft. in clear span.

Cut-back Products.—Petroleum, or tar residuums, which have been fluxed, each with its own or similar distillates.

Dead Oils.—Oils with a density greater than water which are distilled from tars.

Ditch.—The open-side drain of a roadway, usually deep in proportion to its width, and unpaved.

Drainage.—Provision for the disposition of water. Side drainage. That along the sides of the roadway. Sub- or under-drainage. That below the surface. Surface drainage. That on the roadway or ground surface. V-drainage. That provided by the construction of troughs in the subgrade of the roadway, which troughs are like a "V," with flat sloping sides, and are filled with stone.

Dust Layer.—Material applied to a roadway for temporarily preventing the formation or dispersion under traffic of distributable dust.

Earth Road.—A roadway composed of natural earthy material.

Emulsion.—A combination of water and oily material made miscible with water through the action of a saponifying or other agent.

Expansion Joint.—A separation of the mass of a structure, usually in the form of a joint filled with elastic material, which will provide opportunity for slight movement in the structure.

Fat.—Containing an excess. A fat asphalt mixture is one in which the asphalt cement is in excess and the excess is clearly apparent.

Fixed Carbon.—The organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen.

Flour.—Finely ground rocks or minerals pulverized to an impalpable product.

Flushing.—(1) Completely filling the voids. (2) Washing a pavement with an excess of water.

Flush Coat.—See "Seal Coat."

Flux.—Bitumens, generally liquid, used in combination with harder bitumens for the purpose of softening the latter.

Footway.—The portion of the highway devoted especially to pedestrians. A sidewalk.

Foundation.—The portion of the roadway below and supporting the crust or pavement.

Artificial Foundation.—That layer of the foundation especially placed on the subgrade for the purpose of reinforcing the supporting power of the latter itself, and composed of material different from that of the subgrade proper.

Natural Foundation.—The natural earthy material below and supporting the artificial foundation or, if there is no artificial foundation, the crust or pavement.

Free Carbon in Tars.—Organic matter which is insoluble in carbon disulphide.

Gas-house Coal Tar.—Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Grade.—(1) The profile of the center of the roadway, or its rate of rise or fall. (2) Elevation. (3) To establish a profile by cuts and fills or earthwork. (4) To arrange by sizes, broken stone, gravel, sand, or combinations of such materials.

Granite.—A granitoid igneous rock consisting of quartz, orthoclase, more or less oligoclase, biotite and muscovite.

Granitoid.—A textural term to describe those igneous rocks which are entirely composed of recognizable minerals.

Gutter.—The artificially surfaced and generally shallow waterway provided usually at the sides of the roadway for carrying surface drainage. Occasionally used synonymously with "ditch," but incorrectly so, as "gutters" are always paved or otherwise surfaced, and ditches are not.

Haunches.—The sides or flanks of a roadway. Sometimes also called "quarters."

Highway.—The entire right of way devoted to public travel, including the sidewalks and other public spaces, if such exist.

Layer.—A course made in one application.

Liquid Bituminous Materials.—Those having a penetration at 25°C. (77°F.), under a load of 100 grams applied for 5 sec., of more than 10,

and a penetration at 25°C. (77°F.), under a load of 50 grams applied for 1 sec., of not more than 350.

Macadam.—A road crust composed of stone or similar material broken into irregular angular fragments compacted together so as to be interlocked and mechanically bound to the utmost possible extent.

Mastic.—A mixture of bituminous material and fine mineral matter suitably made for use in highway construction and for application in a heated condition.

Mat.—See "Carpet."

Matrix.—The binding material or mixture of binding material and fine aggregate in which the large aggregate is embedded or held in place.

Mesh.—The square opening of a sieve.

Metal.—See "Road Metal."

Mortar.—A mixture of fine material such as sand, cement, and water or other liquid suitably proportioned and incorporated together for the purpose for which it is used.

Mush.—A greasy mud sometimes found on bituminous crusts.

Normal Temperature.—As applied to laboratory observations of the physical characteristics of bituminous materials, is 25°C. (77°F.).

Oil-gas Tars.—Tars produced by cracking oil vapors at high temperatures in the manufacture of oil gas.

Palliative.—A short-lived dust layer.

Patching.—Repairing or restoring small isolated areas in the surface of the metaled or paved portion of the highway.

Pavement.—The wearing course of the roadway or footway, when constructed with a cement or bituminous binder, or composed of blocks or slabs, together with any cushion or "binder" course.

Penetration.—The consistency of a bituminous material expressed as the distance that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. Where the conditions of test are not specifically mentioned, the load, time and temperature are understood to be 100 grams, 5 sec., 25°C. (77°F.) and the units of penetration to indicate hundredths of centimeters.

Penetration Method.—The method of constructing a bituminous macadam pavement by pouring or grouting the bituminous material into the upper course of the road metal before the binding of the latter has been completed.

Petroleum.—Liquid bitumen occurring as such in nature.

Pitches.—Solid residues produced in the evaporation or distillation of bitumens, the term being usually applied to residues obtained from tars.

Hard pitch.—Pitch showing a penetration of not more than ten.

Soft pitch.—Pitch showing a penetration of more than ten.

Pocket.—A hole or depression in the wearing course.

Pot-hole.—A hole extending below the wearing course.

Profile.—A longitudinal section of a highway, generally taken along the center line.

Quarters.—The four sections of equal width which, side by side, make up the total width of a roadway.

Raveling.—The loosening of the metal composing the crust.

Refined Tar.—Tar freed from water by evaporation or distillation which is continued until the residue is of desired consistency; or a product produced by fluxing tar residuum with tar distillate.

Renewals.—Extensive repairs over practically the whole surface of the metaled or paved portion of the highway.

Repairs.—The restoration or mending of a considerable amount of the metaled or paved portion of the highway, but not usually of a majority of the surface area. More extensive than "Patching" but less so than "Renewals."

Resurfacing.—The renewal of the surface of the crust or pavement.

Road.—A highway outside of an urban district.

Roadbed.—The natural foundation of a roadway.

Road Metal.—Broken stone, gravel, slag, or similar material used in road and pavement construction and maintenance.

Roadway.—That portion of a highway particularly devoted to the use of vehicles.

Rock Asphalt.—Sandstone or limestone naturally impregnated with asphalt.

Rock-asphalt Pavement.—A wearing course composed of broken or pulverized rock asphalt with or without the addition of other bituminous materials.

Rubble.—Rough stones of irregular shapes and sizes, broken from larger masses either naturally or artificially, as by geological action, in quarrying, or in stone cutting or blasting.

Sand-clay Road.—A roadway composed of an intimate mixture of sand and clay.

Scarify.—To loosen and disturb superficially.

Seal Coat.—A final superficial application of bituminous material during construction to a bituminous pavement.

Setting Up.—The relatively quick change such as takes place in a bituminous material after its application to a roadway, indicated by its hardening after cooling and exposure to atmospheric and traffic conditions, as opposed to the slower changes later occurring gradually and almost imperceptibly.

Shaping.—Trimming up and preparing a subgrade preparatory to applying the first course of the road metal or artificial foundation.

Sheet-asphalt Pavement.—One having a wearing course composed of asphalt-cement and sand of predetermined grading, with or without the addition of fine material, incorporated together by mixing methods.

Sheet Pavement.—A pavement free from frequent joints such as would accompany small slabs or blocks, and which has an appreciable thickness (say in excess of 1 in. on the average) for its wearing course.

Shoulders.—The portion of the highway between the edges of the road metal or pavement and the gutters, slopes, or watercourse.

Side Drain.—See "Drainage."

Sidewalk.—The portion of the highway reserved for pedestrians.

Slag.—Fused or partly fused compounds of silica in combination with lime or other bases, resulting in secondary products from the reduction of metallic ores.

Soil.—A mixture of fine earthy materials with more or less organic matter resulting from the growth and decomposition of vegetation or animal matter.

Solid Bituminous Materials.—Those having a penetration at 25°C. (77°F.), under a load of 100 grams applied for 5 sec., or not more than 10.

Spalls.—Fragments broken off by a blow, irregular in shape, and of sufficient size to be comparable to the original mass.

Squeegee.—A tool with a rubber or leather edge for scraping or cleaning hard surfaces, or for spreading and distributing liquid material over and into the superficial interstices of roadways.

Squeegee Coat.—An application by means of the squeegee.

Stone Chips.—Small angular fragments of stone containing no dust.

Straight-run Pitch.—A pitch run to the consistency desired, in the initial process of distillation, without subsequent fluxing.

Street.—A highway in an urban district.

Subgrade.—The upper surface of the native foundation on which is placed the road metal or the artificial foundation, in case the latter is provided.

Superficial Coat.—A light surface coat.

Surface Coat.—See "Carpet."

Surface Treatment.—Treating the finished surface of a roadway with bituminous material.

Tailings.—Stones which after going through the crusher do not pass through the largest openings of the screen.

Tars.—Bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens, pyrobitumens or organic materials.

Dehydrated Tars.—Tars from which all water has been removed.

Telford.—Properly, an artificial foundation advocated by Thomas Telford (1757–1820), and consisting of a pavement of stone about 8 in. thick, laid by hand, and closely packed and wedged together. The individual stones were desired to be about 16 sq. in. in section, and about 8 in. in length. They were set close together on the prepared subgrade, their longest dimension vertical and on their larger ends, their interstices chinked with smaller stones, and the whole rammed (or rolled) until firm and unyielding.

Telford Macadam.—Macadam with an artificial foundation of Telford.

Topped Petroleum.—Petroleum deprived of its more volatile constituents.

Under-drain.—See "Drainage."

Up-keep.—Maintenance.

V-drain.—See "Drainage."

Viscosity.—The measure of the resistance to flow of a bituminous material, usually stated as the time of flow of a given amount of the material through a given orifice.

Volatile.—Applied to those fractions of bituminous materials which will evaporate at climatic temperatures.

Water-bound.—Bound or bonded with the aid of water.

Water-gas Tars.—Tars produced by cracking oil vapors at high temperatures in the manufacture of carburetted water gas.

Wearing Coat.—The superficial layer of the crust or pavement exposed to traffic.

Wearing Course.—The course of the crust or pavement exposed to traffic.

Wood-block Pavement.—One having a wearing course composed of wood paving blocks, generally rectangular in shape.

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